Thi- Qar University
College of Engineering
Mechanical Engineering Department

Machine Design

4th Year Students
(Manual solutions)
Of machine design text book
by
KHURMI and GUPTA

Solved by :
Eng . YOUNIS FAKHER

2010- 2011

Solutions of Problems - Chapter 4

1- Given: $P = 65\,kN = 65*10^3\,N$, $\sigma = 35\,N/mm^2$, $d = ?$

$\sigma = P/A \Rightarrow 35 = 65*10^3/(\frac{\pi}{4}d^2) \Rightarrow d = 48.6\,mm$, Say $d = 50\,mm$

2- $\sigma_{max} = P_{max}/A \Rightarrow 30 = \frac{580}{\frac{\pi}{4}d^2} \Rightarrow d = 4.9\,mm \simeq 5\,mm$

3- $\sigma_{permissible} = \frac{P}{A} \Rightarrow 52.5 = \frac{350*10^3}{\frac{\pi}{4}d^2} \Rightarrow d = 92.13$ Say $95\,mm$

4- $\sigma = \frac{P}{A} \Rightarrow 100 = \frac{5*10^3}{\frac{\pi}{4}d^2} \Rightarrow d = 7.9\,mm \simeq 8\,mm$

5- $\sigma_{bar} = P/A_{bar} \Rightarrow P = \sigma_{bar} * A_{bar} = 150(20*20) = 60*10^3\,N$

P for each bolt $= 60*10^3/6 = 10\,000\,N$

$\sigma_{bolt} = P_{bolt}/A_{bolt} \Rightarrow 75 = 10\,000/(\frac{\pi}{4}d^2)$

$d = 13.029\,mm$ say $13\,mm$

6- $P = P_r * A = 0.7 * \frac{\pi}{4}(300)^2 = 49.48\,kN$

$\sigma = P/A \Rightarrow 40 = 49.48/(\frac{\pi}{4}d^2) \Rightarrow d = 39.68 \simeq 40\,mm$

7- $\sigma_t = P/A = 120*10^3/(\frac{\pi}{4}(50^2)) = 61.115\,N/mm^2$

$\tau = P/2A = 120*10^3/(2*\frac{\pi}{4}(40^2)) = 47.75\,N/mm^2$

8- $\sigma_t = P/A \Rightarrow P = 1200*\frac{\pi}{4}d^2 = 300\pi d^2$

$\tau = P/A = \frac{300\pi d^2}{\pi d t} = \frac{300\pi d}{\pi * 20} \Rightarrow d = 20\,mm$

9- $\sigma_b = \frac{P}{L.d} = \frac{35*10^3}{1.2d*d} \Rightarrow 7 = \frac{35*10^3}{1.2d^2} \Rightarrow d = 64.55\,mm$

$L = 1.2d = 1.2*64.55 = 77.46 \simeq 80\,mm$

10- $A = \frac{\pi}{4} d^2 = \frac{\pi}{4}(20)^2 = 314\ mm^2$

$\sigma = P/A = 80000/314 = 254.77\ N/mm^2$

$\epsilon = \delta l / L_o = 0.048/40 = 0.0012$

$E = \sigma/\epsilon = 254.77/0.0012 = 212308.33\ N/mm^2 = 212.308\ kN/mm^2$

σ_{yield} = load at yield point / $A = 85*10^3/314 = 270.56\ N/mm^2$

$\sigma_{ultimate}$ = maximum load / $A = 150*10^3/314 = 477.5\ N/mm^2$

Percentage elongation $= \frac{55.6-40}{40} * 100 = 39\ \%$

Percentage reduction in area $= \frac{A_o - A_f}{A_o} = \frac{20^2 - 12.4^2}{20^2} = 37.6\ \%$

11- case(1): $d_{s1} = 25\ mm$, $d_{b_o} = 37.5\ mm$, $d_{b_i} = 25\ mm$

$A_{s1} = \frac{\pi}{4} d^2 = \frac{\pi}{4}(25)^2 = 490.87\ mm^2$, $A_{b1} = \frac{\pi}{4}(d_o^2 - d_i^2) = 613.6\ mm^2$

$\sigma_{s1} = F/A_s = 10.186\ MPa$, $\sigma_{b1} = 8.15\ MPa$

case(2): after turning:

$d_{o_{b_2}} = 25+8 = 33\ mm$, $A_{b2} = 364.6\ mm^2$, $A_{s_2} = A_{s_1} = 490.87\ mm^2$

$F_{s_2} = F_{b2} \Rightarrow \sigma_{s_2} \cdot A_{s_2} = \sigma_{b_2} \cdot A_{b2} \Rightarrow \sigma_{b2} = \frac{490.87}{364.6} \cdot \sigma_{s2}$

$\sigma_{b2} = 1.34\ \sigma_{s_2}$ ---- (1)

$\delta l_{net_s} = \delta l_{net_b}$

$\delta l_{s_2} - \delta l_{s_1} = \delta l_{b_2} - \delta l_{b_1}$

$\left(\frac{P.L}{A.E}\right)_{s_2} - \left(\frac{P.L}{A.E}\right)_{s_1} = \left(\frac{P.L}{A.E}\right)_{b_2} - \left(\frac{P.L}{A.E}\right)_{b_1}$

$\frac{\sigma_{s_2} - \sigma_{s_1}}{E_s} = \frac{\sigma_{b_2} - \sigma_{b_1}}{E_b} \Rightarrow \frac{\sigma_{s_2} - 10.186}{200*10^3} = \frac{\sigma_{b_2} - 8.15}{90*10^3}$

$200\ \sigma_{b_2} - 1630 = 90\ \sigma_{s_2} - 916.74$

$200(1.34\ \sigma_{s_2}) - 1630 = 90\ \sigma_{s_2} \Rightarrow \sigma_{s_2} = 3.98 \simeq 4\ MPa$

$\therefore \sigma_{b_2} = 3.98 * 1.34 = 5.356\ MPa$

"Machine Design"

12- $\Delta t = t = 97-47 = 50^\circ C$

$\delta_{al(th)} = \alpha . t . l = 24*10^{-6} * 50 * 100 = 120\,000 * 10^{-6}$ mm

$\delta_{s(th)} = \alpha . t . l = 12*10^{-6} * 50 * 150 = 90\,000 * 10^{-6}$ mm

$\delta_{net(th)} = (120\,000 - 90\,000) * 10^{-6} = 30\,000 * 10^{-6}$ mm

$\delta_{force(net)} = \delta_{al} + \delta_{st} = \left(\frac{P.L}{A.E}\right)_{al} + \left(\frac{(P-200000)L}{A.E}\right)_{st}$

$30\,000*10^{-6} = \frac{P*100}{1000*70*10^3} + \frac{(P-200000)*150}{1500*210*10^3} \Rightarrow P = 65\,750\,N$

$\sigma_{al} = P/A = 65\,750$ N/mm^2 , $\sigma_{s_1} = 65750/1500 + \frac{200\,000}{1500} = 177.16$ N/mm^2

13- $A_s = \frac{\pi}{4} d^2 = 314.16$ mm^2, $A_c = \frac{\pi}{4}(d_o^2 - d_i^2) = \frac{\pi}{4}(40^2 - 20^2) = 942.5$ mm^2

$\delta_c = \alpha_c . t . l = 18*10^{-6} * 50 * l = 900*10^{-6} l$ mm

$\delta_s = \alpha_s . t . l = 12*10^{-6} * 50 * l = 600*10^{-6} l$ mm

$\delta_{net(th)} = (900-600)*10^{-6} l = 300*10^{-6} l$ mm

$\delta_{net(force)} = \left(\frac{P.L}{A.E}\right)_s + \left(\frac{P-50\,000}{A.E}\right)_c * l$

$= \frac{P.l}{314.16*200*10^3} + \frac{P.l}{942.5*100*10^3} - \frac{50\,000 * l}{942.5*100*10^3}$

$= 2.661*10^{-8} * P * l - 53050.4 * l * 10^{-8}$

$\delta_{net(force)} = \delta_{net(th)}$

$2.661*10^{-8} P.l - 53050.4 l*10^{-8} = 300*10^{-6} l$

$P = 31210.22\,N$

$\sigma_s = P/A_s = 31210.22/314.16 = 99.345$ N/mm^2 ans.

$\sigma_c = P/A_c = 31210.22/942.5 = 33.1$ N/mm^2

$\sigma_{c\,comp} = F/A_c = 50000/942.5 = 53.5$ N/mm^2

$\sigma_{net} = 53.5 - 33.1 = 20$ N/mm^2 ans.

14- $\sigma = E\epsilon$, $\epsilon = \sigma/E$, $\epsilon = \frac{P}{A}/E = 30*1000/20*15*200*10^3$

$\epsilon = 5*10^{-4}$

$\epsilon_v = \epsilon(1-2\mu) = 5*10^{-4}(1-2*0.25) = 2.5*10^{-4}$

$\epsilon_v = \delta v/V_o \Rightarrow \delta v = V_o . \epsilon v = 2000*20*15*2.5*10^{-4} = 150\ mm^3$

$V_o = 2000*15*20 = 600*10^3\ mm^3$

$V_{final} = V_o + \delta v = 600*10^3 + 150 = 600150\ mm^3$ ans.

15- $\delta l = \frac{P.l}{A.E} \Rightarrow L = \frac{\delta l . A . E}{P} = 3*\frac{\pi}{4}(12)^2*200*10^3 / 8000 = 8482.3\ mm$

$\sigma_i = \frac{W}{A}\left[1+\sqrt{1+\frac{2AEh}{W.L}}\right]$

$= \frac{800}{\frac{\pi}{4}(12)^2}\left[1+\sqrt{1+\frac{2*\frac{\pi}{4}(12)^2*200*10^3*80}{800*8482.3}}\right] = 170.583 = 170.6\ N/mm^2$ ans

Solutions of Problems - Chapter 5

1- $\frac{T}{J}=\frac{\tau}{r}=\frac{G.\theta}{L} \Rightarrow \frac{T}{J}=\frac{\tau}{r} \Rightarrow \tau=\frac{T}{J}.r$

$\tau=\frac{1100*1000}{\frac{\pi}{32}(d)^4}*\frac{d}{2} \Rightarrow \tau=\frac{16*1100*100}{\pi(50)^3}=44.8\ MPa$

$\frac{\tau}{r}=\frac{G.\theta}{L} \Rightarrow G=\frac{\tau.L}{r.\theta}=\frac{44.8*500}{25*0.6*\frac{\pi}{180}}=85.6\ kN/mm^2$

2- $T=\frac{P}{\omega}=\frac{100*1000}{6\pi}=5.31*10^3\ N.m=5.31*10^6\ N.mm$

when $\omega=2\pi N/60=6\pi$ rad/sec

For strength :

$\frac{T}{J}=\frac{\tau}{r} \Rightarrow \frac{5.31*10^6}{\frac{\pi}{32}(d)^4}=\frac{60}{d/2} \Rightarrow d=76.67\ mm$

OR

For stiffness:

$\frac{T}{J}=\frac{G.\theta}{L} \Rightarrow \frac{5.31*10^6}{\frac{\pi}{32}(d)^4}=\frac{80*10^3*1^\circ*\frac{\pi}{180}}{3000} \Rightarrow d=105\ mm$ ans.

for design we choose the greater , i.e $d=105\ mm$

3- $T=\frac{P}{\omega}=\frac{90*10^3}{6\pi}=4.775*10^3\ N.m=4.775*10^6\ N.mm$

$T_{max}=T*1.4=4.775*1.4*10^6=6.684*10^6\ N.mm$

For strength

$\frac{T}{J}=\frac{\tau}{r} \Rightarrow \frac{6.684*10^6}{\frac{\pi}{32}(d)^4}=\frac{70}{d/2} \Rightarrow d=78.6\simeq 80\ mm$

$\frac{T}{J}=\frac{G.\theta}{L} \Rightarrow \frac{6.684*10^6}{\frac{\pi}{32}(d)^4}=\frac{90*10^3*\theta}{2000} \Rightarrow \theta=0.037\ rad$

$\theta^\circ=0.037*\frac{\pi}{180}=2.116^\circ$ ans:

4- $\omega = \frac{2\pi N}{60} = 10\pi$ rad/sec

$$T = \frac{P}{\omega} = \frac{11.2 * 10^3}{10\pi} = 356.51 * 10^3 \text{ N.m} = 356.51 * 10^6 \text{ N.mm}$$

$$\frac{T}{J} = \frac{\tau}{r} \Rightarrow \frac{356.51 * 10^6}{\frac{\pi}{32}(d_o^4 - d_i^4)} = \frac{80}{d_o/2}$$

$d_i = \frac{3}{4} d_o$

$$\frac{356.51 * 10^6}{\frac{\pi}{32}\left[d_o^4 - (\frac{3}{4}d_o)^4\right]} = \frac{80}{d_o/2}$$

$d_o = 321.4$ mm , $d_i = 241$ mm

By correcting the results, we obtain:

$d_o = 320$ mm , $d_i = 240$ mm ans.

5- $V_{solid} = \frac{\pi}{4} d_o^2 * l$

$V_{hollow} = \frac{\pi}{4}[d_o^2 - d_i^2] * l = \frac{\pi}{4}[d_o^2 - (\frac{2}{3}d_o)^2] * l$

$= \frac{\pi}{4} \cdot d_o^2 [1 - \frac{4}{9}] * l = \frac{\pi}{4} d_o^2 * \frac{5}{9} * l$

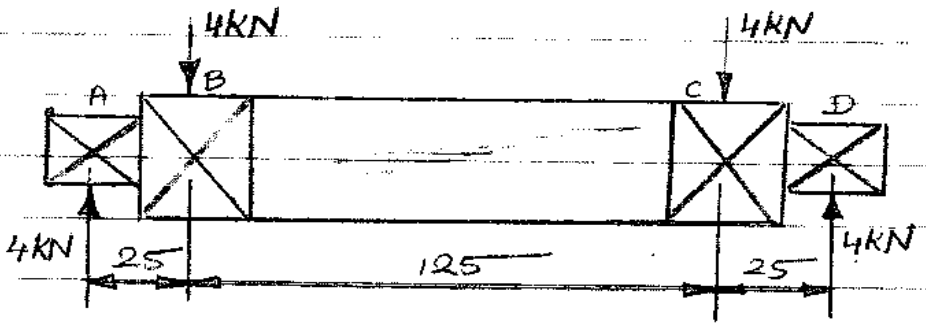
$m = \rho v \Rightarrow W = \rho v g$

$W_{solid} = \rho \cdot V_{solid} \cdot g$, $W_{hollow} = \rho \cdot V_{hollow} \cdot g$

$$\frac{W_{hollow}}{W_{solid}} = \frac{\rho \cdot V_{hollow} \cdot g}{\rho \cdot V_{solid} \cdot g} = \frac{V_{hollow}}{V_{solid}} = \frac{\frac{\pi}{4} * \frac{5}{9} * d_o^2 * l}{\frac{\pi}{4} * d_o^2 * l} = \frac{5}{9}$$

$= 0.56$ ans.

6-



Bending Moment at A = 0

" " " B = 4 * 25 = 100 KN.mm (↻)

" " " C = 4 * 150 − 4 * 125 = 100 (↺)

" " " D = 0

∴ Maximum Bending Moment = 100 KN.mm (at B & C)

$$\frac{M}{I} = \frac{\sigma}{y}$$

$$\frac{100*10^3}{\frac{\pi}{64} d^4} = \frac{120}{d/2} \Rightarrow d = 20.4 \simeq 21 \text{ mm}$$

7- $\omega = \frac{2\pi N}{60} = 10\pi$ rad/sec

$T = P/\omega = 20*10^3 / 10\pi = 6.4*10^3 \text{ N.m} = 6.4*10^5 \text{ N.mm}$

$F = \frac{T}{R} = \frac{6.4*10^5}{275/2} = 2.327*10^3 \text{ N}$

$F_{(\text{for arm})} = 2.327*10^3 / 4 = 0.582*10^3 \text{ N} = 582 \text{ N}$

Moment on each arm $= F_{arm} * R = 582 * 275 = 160050$ N.mm

$$\frac{M}{I} = \frac{\sigma}{y}$$

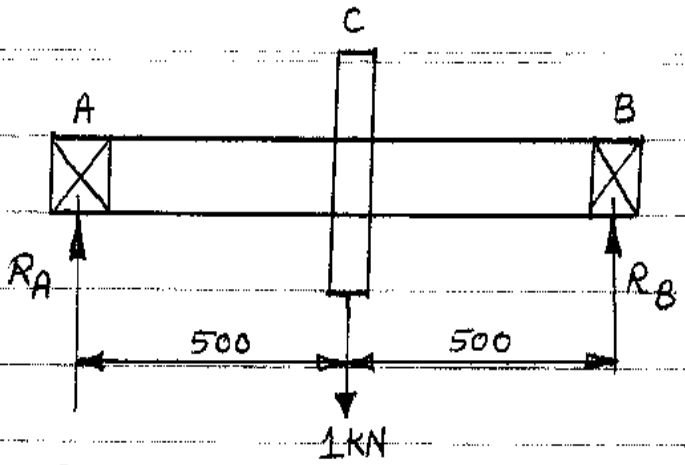
$$\frac{160050}{\frac{\pi}{4} * a * b^3} = \frac{15}{\frac{b}{2}}$$

$b = 32.4 \text{ mm} \simeq 32 \text{ mm}$ ans.

$a = 2b = 2*32 = 64 \text{ mm}$ ans.

"Machine Design"

8-



$l = 1\,m = 1000\,mm$

$AC = CB = 500\,mm$

$\Sigma M_B = 0 \Rightarrow R_A = 0.5 * 10^3\,N = R_B$

Bending Moment at point A = 0

" " " " $C = R_A * 500 = 500 * 500 = 250 * 10^3\,N.mm$

" " " " $B = 0$

Maximum bending Moment at the point $C = 250 * 10^3\,N.mm$

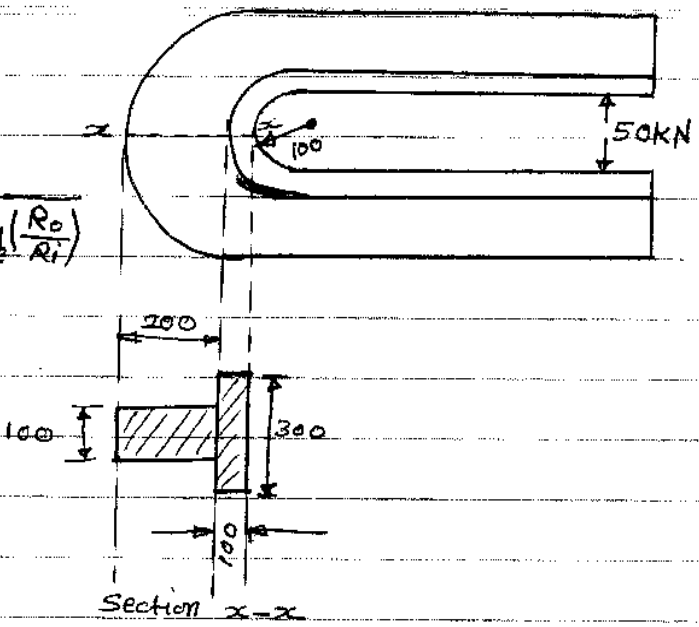
$$\frac{M}{I} = \frac{\sigma}{y}$$

$$\frac{250 * 10^3}{\frac{\pi}{64} d^4} = \frac{40}{d/2} \Rightarrow d = 39.93 \simeq 40\,mm$$

"Machine Design"

9- By Using table 5.2

$$R_n = \frac{t_i(b_i - t) + t \cdot h}{(b_i - t)\cdot \log_e\left(\frac{R_i + t_i}{R_i}\right) + t \cdot \log_e\left(\frac{R_o}{R_i}\right)}$$



$t_i = 100$, $b_i = 300$, $t = 100$

$h = 300$, $R_i = 100$, $R_o = 400$

$$R_n = \frac{100(300-100) + 100*300}{(300-100)\ln\left(\frac{100+100}{100}\right) + 100*\ln\left(\frac{400}{100}\right)}$$

$= 180.337$ mm

$$R = R_i + \frac{\frac{1}{2}h^2 t + \frac{1}{2}t_i^2(b_i - t)}{h \cdot t + t_i(b_i - t)} = 100 + \frac{\frac{1}{2}(300)^2 100 + \frac{1}{2}(100)^2(300-100)}{300*100 + 100(300-100)} = 210 \text{ mm}$$

$e = R - R_n = 210 - 180.337 = 29.663$ mm

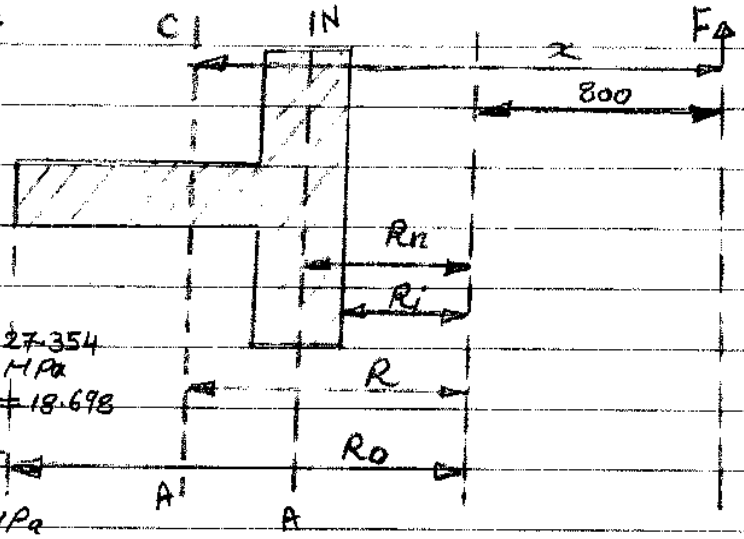
$y_i = R_n - R_i = 180.337 - 100 = 80.337$ mm (from e to inner surface)

$y_o = R_o - R_n = 400 - 180.337 = 219.663$ mm

$x = x_o + R = 800 + 210 = 1010$ mm (the distance to C.A)

$A = 100*300 + 200*100 = 50000 \text{ mm}^2$

$\sigma_t = F/A = 50000/50000 = 1$ MPa



Bending Moment about C.A:

$M = F * x = 50000 * 1010$

$= 50.5 * 10^6$ N.mm

$$\sigma_{bi} = \frac{M \cdot y_i}{A \cdot e \cdot R_i} = \frac{50.5*10^6 * 80.337}{50000 * 29.663 * 100} = 27.354 \text{ MPa}$$

$$\sigma_{bo} = \frac{M \cdot y_o}{A \cdot e \cdot R_o} = \frac{50.5*10^6 * 219.663}{50000 * 29.663 * 400} = 18.698$$

$\sigma_{R_i} = \sigma_t + \sigma_{bi} = 1 + 27.354 = 28.35$

$\sigma_{R_o} = \sigma_t - \sigma_{bo} = 1 - 18.698 = 17.7$ MPa

10- $R_i = 65\ mm$, $R_o = 65 + 116 = 181\ mm$

$A = \frac{1}{2}(90+25)*116 = 6670\ mm^2$

R_n = from table 5.2

$$= \frac{\left[\frac{b_i+b_o}{2}\right]h}{\left(\frac{b_i R_o - b_o R_i}{h}\right)\ln\left(\frac{R_o}{R_i}\right) - (b_i - b_o)}$$

$$= \frac{\left[\frac{90+25}{2}\right]*116}{\left[\frac{90*181 - 25*65}{116}\right]*\ln\left(\frac{181}{65}\right) - (90-25)}$$

$= 103.48\ mm$

$$R = R_i + \frac{h(b_i+2b_o)}{3(b_i+b_o)}$$

$$= 65 + \frac{116(90+2*25)}{3(90+25)} = 112.072\ mm$$

$e = R - R_n = 112.072 - 103.48 = 8.592\ mm$

$x = R = 112.072\ mm$

$M = P*x = 90*10^3*112.072 = 10086480\ N.mm$

$\sigma_t = P/A = \frac{90*10^3}{6670} = 13.493\ N/mm^2$

$y_i = R_n - R_i = 103.48 - 65 = 38.48\ mm$

$y_o = R_o - R_n = 181 - 103.48 = 77.52\ mm$

$\sigma_{bi(P)} = \frac{M.y_i}{A.e.R_i} = \frac{10086480*38.48}{6670*8.592*65} = 104.193\ mm$

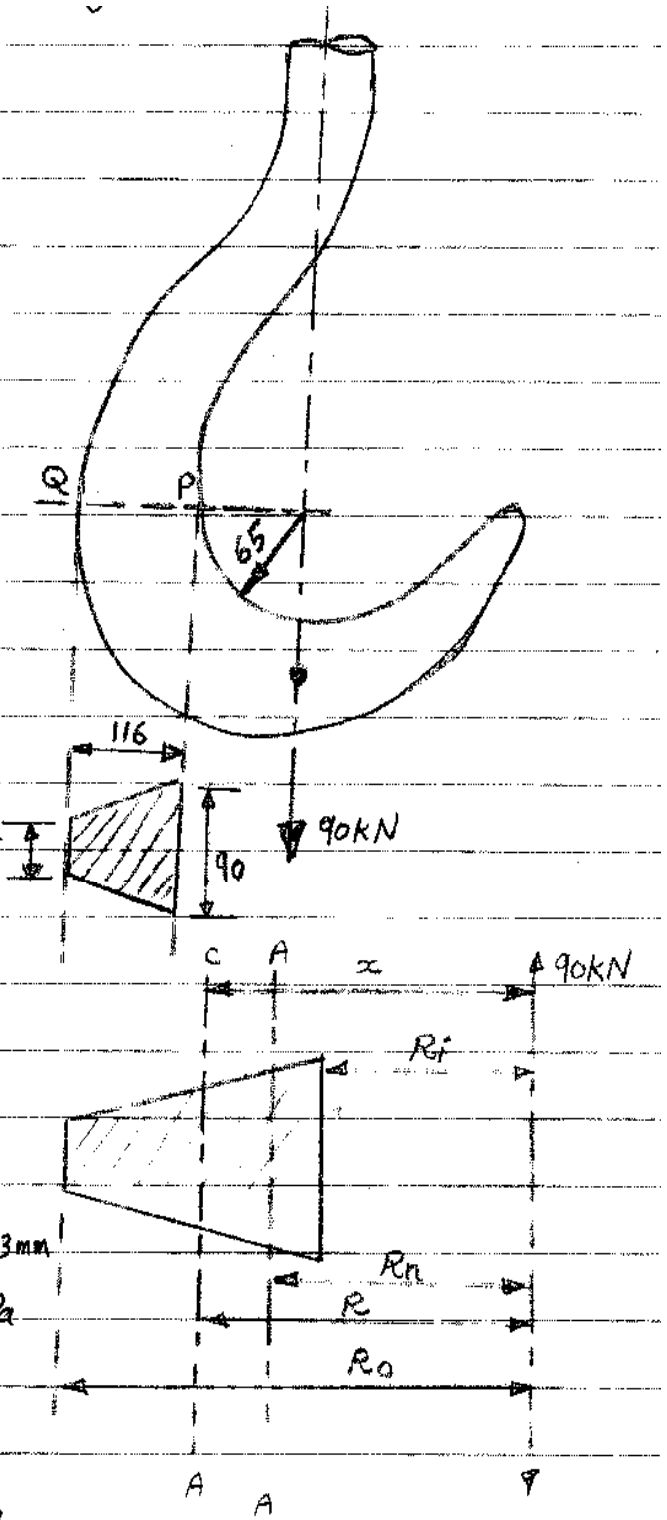
$\sigma_{R_i} = \sigma_t + \sigma_{bi} = 13.493 + 104.193 = 118\ MPa$

$\sigma_{bo(Q)} = \frac{M.y_o}{A.e.R_o}$

$$= \frac{10086480*77.5}{6670*8.592*181} = 75.379\ MPa$$

$\sigma_{R_o} = \sigma_t - \sigma_{bo(Q)} = 13.493 - 75.379$

$= 61.8 \simeq 62\ MPa$



"Machine Design"

11- Given : $d=16\,mm$, $P_t=5000N$, $T=50N.m=50*10^3\,N.mm$, $M=75N.m=75*10^3\,N.mm$

$A=\frac{\pi}{4}d^2=\frac{\pi}{4}(16)^2=200.96\,mm^2$

(a) Max. stress theory:

$\sigma_o=P/A=5000/200.96=24.88\ N/mm^2$

$Z=\frac{\pi}{32}d^3=\frac{\pi}{32}(16)^3=401.92$

$\sigma_b=M/Z=75000/401.92=186.604\ N/mm^2$

$\tau=\frac{16T}{\pi d^3}=\frac{16*50*10^3}{3.14(16)^3}=62.20\ N.mm$

$\sigma_R=\sigma_o+\sigma_b=186.604+24.88=211.484\ N/mm^2$

$$\sigma_{max}=\frac{\sigma_R}{2}+\frac{1}{2}\sqrt{(\sigma_R)^2+4\tau^2}$$

$$=\frac{211.484}{2}+\frac{1}{2}\sqrt{(211.484)^2+4(62.20)^2}=228.421\ N/mm^2$$

$\sigma_{min}=-16.9373\ N/mm^2$

$FS=\frac{\sigma_{yt}}{\sigma_{max}}=400/228.421=1.7511$ ans.

(b) Max. shear stress theory:

$$\tau_{max}=\frac{1}{2}\sqrt{(\sigma_R)^2+4\tau^2}=\frac{1}{2}\sqrt{(211.484)^2+4(62.20)^2}=122.63\ MPa$$

$$\tau_{max}=\frac{\sigma_{yt}}{2FS}\Rightarrow FS=\frac{400}{2*122.63}=1.63$$

We choose the greater value of $FS=1.7511$ ans.

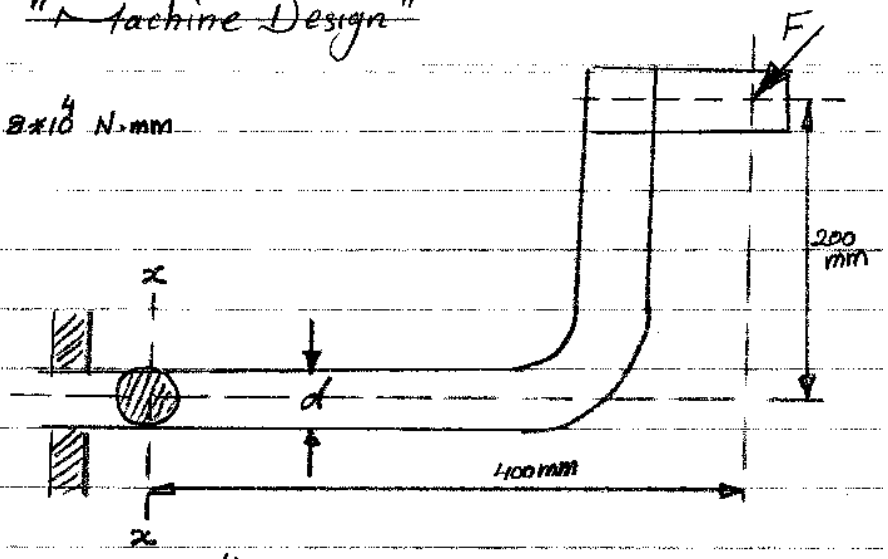
(2) By using distortion energy theory:

$$(\sigma_{t1})^2+(\sigma_{t2})^2-\sigma_{t1}.\sigma_{t2}=\left(\frac{\sigma_{yt}}{FS}\right)^2$$

$$(228.421)^2+(-16.9373)^2-(228.421)*(-16.9373)=\frac{(\sigma_{yt})^2}{(1.686)^2}$$

$\sigma_{yt}=400.15\simeq 400\ MPa.$

"Machine Design"



$F = 400\ N,\ \sigma_y = 320\ MPa$

12- $T = F * 200 = 400 * 200 = 8 * 10^4\ N.mm$

$$\frac{T}{J} = \frac{\tau}{r} \Rightarrow \tau = \frac{T}{J} \cdot r$$

$$\tau = \frac{8*10^4}{\frac{\pi}{32} d^4} * \frac{d}{2}$$

$$= \frac{16 * 8 * 10^4}{\pi d^3}$$

$B.M = F * 400 = 400 * 400$

$= 16 * 10^4\ N.mm$

$$\frac{M}{I} = \frac{\sigma}{y} \Rightarrow \sigma = \frac{M}{I} \cdot y = \frac{16*10^4 * 32}{\pi d^3}$$

$$\sigma_{t_{1,2}} = \frac{\sigma}{2} \mp \frac{1}{2}\sqrt{(\sigma)^2 + 4\tau^2}$$

$$= \frac{16*10^4*32}{\pi d^3} \mp \frac{1}{2}\sqrt{\left(\frac{16*10^4*32}{\pi d^3}\right)^2 + 4\left(\frac{16*8*10^4}{\pi d^3}\right)^2}$$

$$\sigma_{t_1} = \frac{1726*10^3}{d^3}\ N/mm^2$$

$$\sigma_{t_2} = \frac{-96.2*10^3}{d^3}\ N/mm^2$$

① For distortion energy:

$$(\sigma_{t_1})^2 + (\sigma_{t_2})^2 - 2\,\sigma_{t_1} \cdot \sigma_{t_2} = \left(\frac{\sigma_y}{F.S}\right)^2$$

$$\left(\frac{10^3}{d^3}\right)^2 \cdot \left[(1726)^2 + (-96.2)^2 - (1726 * -96.2)\right] = \left(\frac{320}{4}\right)^2$$

$d = 28.36\ mm$ ans:

② For Max. Shear Stress theory:

$$\tau_{max} = \frac{1}{2}\sqrt{(\sigma_{t_1})^2 + 4\tau^2} = \frac{1}{2}\sqrt{\left(\frac{16*10^4*32}{\pi d^3}\right)^2 + 4\left(\frac{16*8*10^4}{\pi d^3}\right)^2} = \left(\frac{\tau_y}{F.S}\right.$$

$$= \frac{16*10^4}{\pi d^3} * \sqrt{320} = \frac{320}{8}$$

$d = 28.34\ mm$ ans:

13- $R_i = 100 - 50 = 50$ mm , $d = 100$ mm (Asume)

$R_o = 100 + 50 = 150$ mm

$$R_n = \frac{(\sqrt{R_o} + \sqrt{R_i})^2}{4} = \frac{(\sqrt{150} + \sqrt{50})^2}{4} = 93.3 \text{ mm}$$

$R = 100$ mm

$e = R - R_n = 100 - 93.3 = 6.7$ mm

$y_i = R_n - R_i = 93.3 - 50 = 43.3$ mm

$y_o = R_o - R_n = 150 - 93.3 = 56.7$ mm

$x = R + Z = 100 + Z$

$$A = \frac{\pi}{4} d^2 = \frac{\pi}{4}(100)^2 = 7854 \text{ mm}^2$$

$$\sigma_t = F/A = \frac{10 * 10^3}{7854} = 1.273 \text{ MPa}$$

Bending Moment at section A–A :

$$M = F * x = F(R + Z)$$

$$= 10 * 10^3 (100 + Z) = 1000 * 10^3 + Z * 10 * 10^3 \text{ N.mm}$$

Max. Bending stress at inner fibre :

$$\sigma_{bi} = \frac{M \cdot y_i}{A \cdot e \cdot R_i}$$

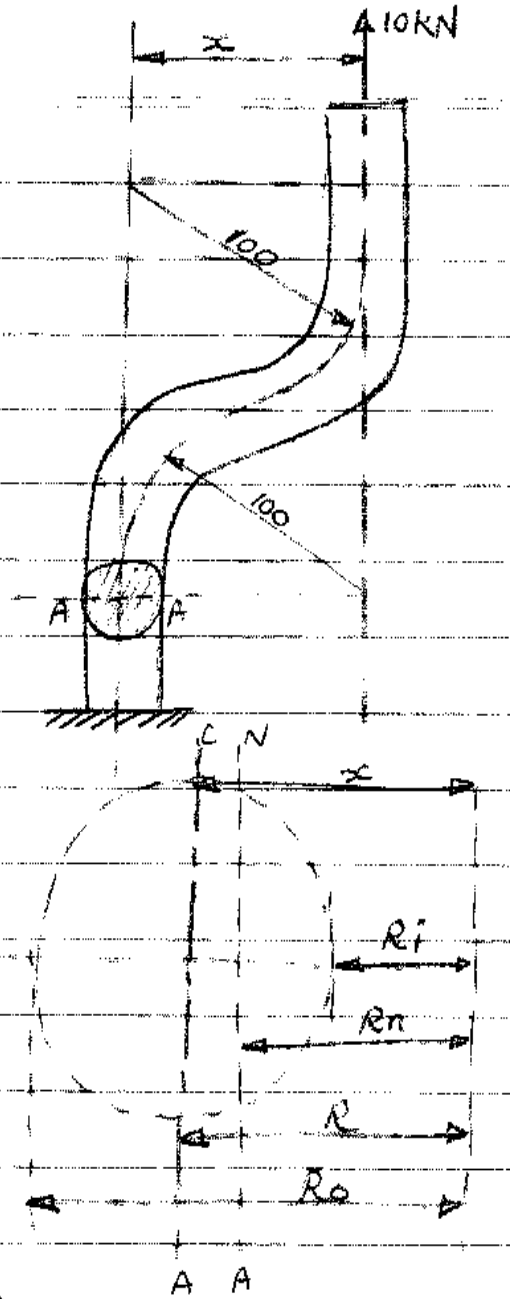
$$= \frac{(1000 * 10^3 + 10 * 10^3 Z) * 43.3}{7854 * 6.7 * 50} = 16.457 + 0.1645 Z$$

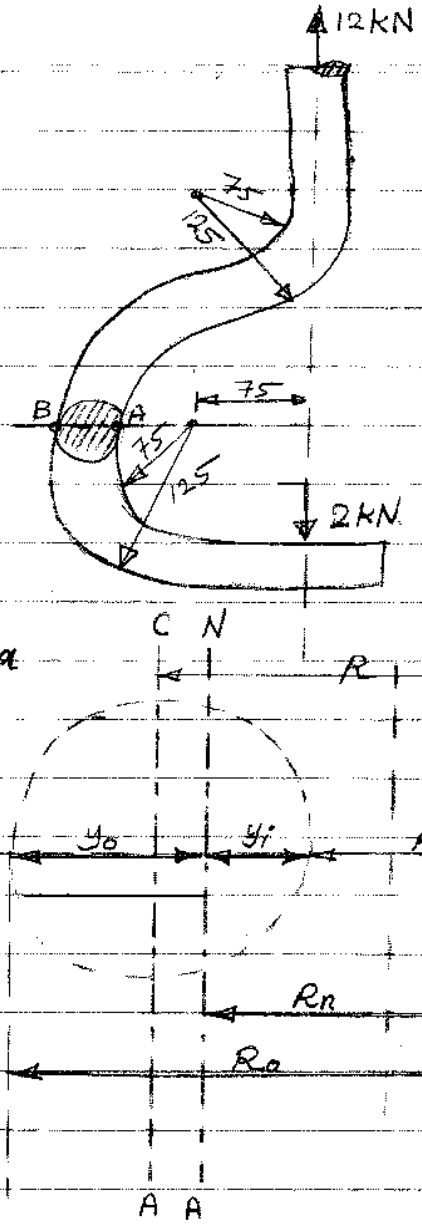
Result stress at inside fibre :

$$\sigma_t + \sigma_{bi} = 1.273 + 1.6457 + 0.1645 Z = 17.73 + 0.1645 Z = 70$$

$Z = 317.62$ mm

$x = R + Z = 100 + 317.62 = 417.62 \simeq 418$ mm





14- $A = \frac{\pi}{4} d^2 = \frac{\pi}{4}(50)^2 = 1963.5\ mm^2$

$$R_n = \frac{(\sqrt{R_o} + \sqrt{R_i})^2}{4}$$

$$= \frac{(\sqrt{125} + \sqrt{75})^2}{4} = 98.4\ mm$$

$R = R_i + \frac{d}{2} = 75 + \frac{50}{2} = 100\ mm$

$e = R - R_n = 100 - 98.4 = 1.6\ mm$

$y_i = R_n - R_i = 98.4 - 75 = 23.4\ mm$

$y_o = R_o - R_n = 125 - 98.4 = 26.6\ mm$

$\sigma_t = \frac{W}{A} = \frac{2*10^3}{1963.5} + \frac{12*10^3}{1963.5} = 7.13\ MPa$

$x = R + 75 = 100 + 75 = 175\ mm$

$M = W * x = 2*10^3 * 175 = 350*10^3\ N.mm$

$$\sigma_{bi_1} = \frac{M \cdot y_i}{A \cdot e \cdot R_i}$$

$$= \frac{350*10^3 * 23.4}{1963.5 * 1.6 * 75} = 34.76\ MPa$$

$$\sigma_{b_{o1}} = \frac{M \cdot y_o}{A \cdot e \cdot R_o}$$

$$= \frac{350*10^3 * 26.6}{1963.5 * 1.6 * 125} = 23.71\ MPa$$

$\sigma_t = \frac{W}{A} = \frac{2*10^3}{1963.5} = 1\ MPa$

∴ Resultant stress at inner surface: (at the point A)

$\sigma_{R_i} = \sigma_t + \sigma_{bi} = 1 + 34.76 = 35.76\ MPa$

Resultant stress at outer Surface:

$\sigma_{R_o} = \sigma_t - \sigma_{b_o} = 1 - 23.71 = -22.71\ MPa$

∴ Max. stress at A = 35.76 MPa ans.

15- $M = F*x = 10*10^3*(25+25+40) = 900*10^3$ N.mm

$$\frac{M}{I} = \frac{\sigma}{y} \Rightarrow \frac{900*10^3}{\frac{\pi}{64}(d)^4} = \frac{\sigma_b}{d/2} \Rightarrow \sigma_b = \frac{900*10^3*32}{\pi(75)^3} = 21.73 \text{ MPa}$$

$T = F*125 = 10*10^3*125 = 1250*10^3$ N.mm

$$\frac{T}{J} = \frac{\tau}{r} \Rightarrow \frac{1250*10^3}{\frac{\pi}{32}(d)^4} = \frac{\tau}{d/2} \Rightarrow \tau = \frac{16*1250*10^3}{\pi(75)^3} = 15.1 \text{ MPa}$$

$$\sigma_{max} = \frac{1}{2}\left[\sigma_{t_1} + \sqrt{(\sigma_{t_1})^2 + 4\tau^2}\right]$$

$$= \frac{1}{2}\left[21.73 + \sqrt{(21.73)^2 + 4(15.1)^2}\right] = 29.46 \text{ MPa} \quad \text{ans.}$$

$$\tau_{max} = \frac{1}{2}\sqrt{(\sigma_{t_1})^2 + 4\tau^2} = \frac{1}{2}\sqrt{(21.73)^2 + 4(15.1)^2} = 18.6 \text{ MPa} \quad \text{ans.}$$

16- $\sigma_t = F/A = \frac{4.5*10^3}{50*t} = \frac{90}{t}$ MPa

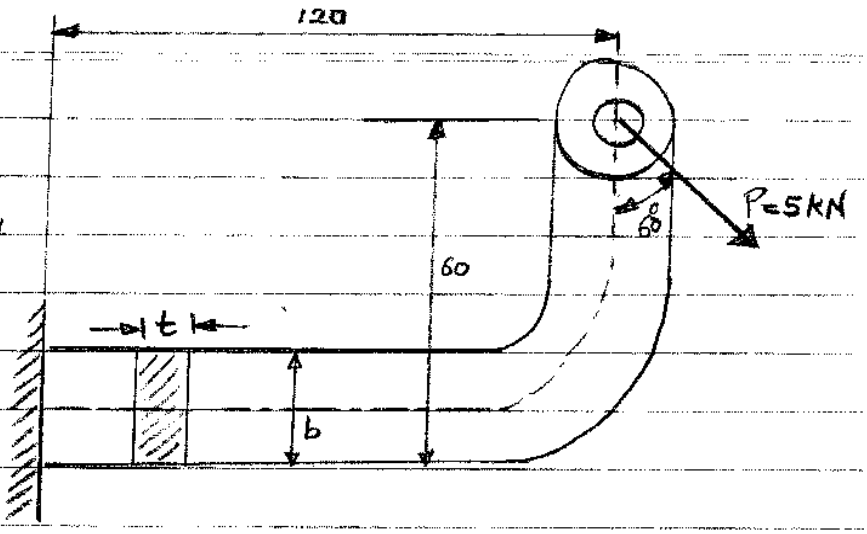
$M = 4.5*10^3*50 = 225*10^3$ N.mm

$$\frac{M}{I} = \frac{\sigma_b}{y} \Rightarrow \frac{225*10^3}{\frac{bh^3}{12}} = \frac{\sigma}{\frac{h}{2}} \qquad b=t,\ h=50\text{mm}$$

$$\sigma_b = \frac{225*10^3*6}{t(50)^2} = \frac{540}{t}$$

$$\sigma_{t\,total} = \sigma_{t_0} + \sigma_b = \frac{90}{t} + \frac{540}{t} = \frac{630}{t}$$

$$70 = \frac{630}{t} \Rightarrow t = 9 \text{ mm} \quad \text{ans.}$$



17- $P = 5\,kN$, $\sigma = 28\,MPa$

$b = 3t$

$P_H = P\sin 60 = 5\sin 60 = 4.33\,kN$

$P_V = P\cos 60 = 5\cos 60 = 2.5\,kN$

$M_H = P_H * 60$

$= 4.33 * 60 = 259.8\,kN.mm$

$M_V = P_V * 120$

$= 2.5 * 120 = 300\,kN.mm$

$$\sigma_{bH} = \frac{M_H}{I} * y = \frac{259.8}{\left(\frac{bh^3}{12}\right)} * \frac{b}{2} = \frac{259.8 * 3t * 10^3}{\frac{t(3t)^3}{12} * 2} = \frac{173.2 * 10^3}{t^3}$$

$$\sigma_{bV} = \frac{M_V}{I} * y = \frac{300 * 10^3}{\frac{t(3t)^3}{12}} * \frac{3t}{2} = \frac{200 * 10^3}{t^3}$$

$$\sigma_{oV} = \frac{P_V}{A} = \frac{2.5 * 10^3}{t(3t)} = \frac{0.833 * 10^3}{t^2}$$

$$\sigma_{Total} = \sigma_{bH} + \sigma_{bV} + \sigma_{oV}$$

$$28 = \frac{173.2 * 10^3}{t^3} + \frac{200 * 10^3}{t^3} + \frac{0.833 * 10^3}{t^2}$$

By using try and error

$t = 24.5 \sim 25\,mm$, $b = 3t = 75\,mm$

Another Solution : $A = b.t = 3t.t = 3t^2$, $Z = \frac{t.b^2}{6} = \frac{t.(3t)^2}{6} = 1.5t^3$

$P_H = 5000\cos 30 = 4330.127\,N$, $M_H = 4330.127 * 60 = 259807.62\,N.mm$

$$\sigma_{bH} = \frac{M_H}{Z} = \frac{259807.62}{1.5t^3} = \frac{173205.08}{t^3}$$

$P_V = 5000 * \sin 30 = 2500N$, $\sigma_{oV} = P_V/A = 2500/3t^2 = \frac{833.33}{t^2}$

$M_V = 2500 * 120 = 300\,000\,N.mm$, $\sigma_{bV} = \frac{M_V}{Z} = 300\,000/1.5t^3 = \frac{200\,000}{t^3}$

$\sigma_{Total} = \sigma_{bV} + \sigma_{bH} + \sigma_{oV}$

$28 = \frac{200\,000}{t^3} + \frac{173205.08}{t^3} + \frac{833.33}{t^2}$, By using try and error method

$t = 25\,mm$, $b = 3t = 75\,mm$ (16)

18- $P_H = P\sin 30 = 0.5P$

$P_V = P\cos 30 = 0.866P$

$M_H = P_H * 50 = 0.5P * 50 = 25P$

$M_V = P_V * 160 = 0.866P * 160 = 138.5P$

$$\sigma_{bH} = \frac{M_H}{I_{xx}} * y = \frac{25P * 12}{30(60)^3} * \frac{60}{2} = 1.389 * 10^{-3} P$$

$$\sigma_{bV} = \frac{M_V}{I_{yy}} * y = \frac{138.5P * 12}{60(30)^3} * \frac{60}{2} = 30.77 * 10^{-3} P$$

$$\sigma_{oV} = P_V/A = 0.866P/1800 = 0.4811P$$

$$\sigma_{Total} = \sigma_{oV} + \sigma_{bH} + \sigma_{bV}$$

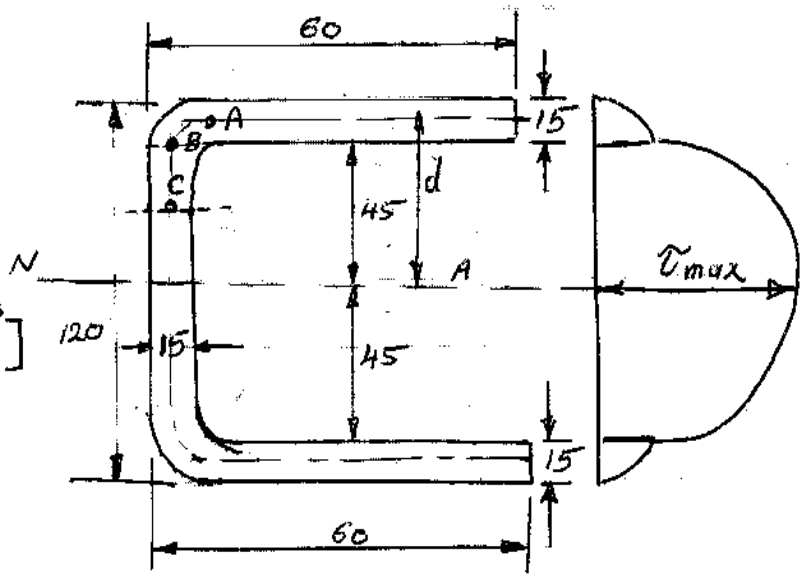
$$70 = P(0.4811 + 1.389 + 30.77) * 10^{-3}$$

$$P = 2422\ N$$

20- Symetric section

C.A = N.A

$$\bar{y} = \frac{\sum A_i y_i}{\sum A_i} = 60$$



$$I = 2\left[\frac{bh^3}{12} + A\cdot d^2\right] + \left[\frac{bh^3}{12}\right]$$

$$I = 2\left[\frac{60(15)^3}{12} + 60*15*(45+7.5)^2\right] + \left[\frac{15*90^3}{12}\right] = 5.91*10^6 \text{ mm}^4$$

shear stress:

At point A:

$$\tau_A = \frac{F\cdot A\cdot \bar{y}}{I\cdot b} = \frac{50*10^3*60*15*(45+7.5)}{5.91*10^6*60} = 6.67 \text{ MPa}$$

At point B:

$$\tau_B = \frac{F\cdot A\cdot \bar{y}}{I\cdot b} = \frac{50*10^3*60*15*(45+7.5)}{5.91*10^6*15} = 26.7 \text{ MPa}$$

At point C:

$$A_{Total} = (60*15)+(45*15) = 1575 \text{ mm}^2$$

$$\bar{y} = \frac{\sum A_i y_i}{\sum A_i} = \frac{(60*15)(45+7.5)+(45*15)*22.5}{1575} = 39.6 \text{ mm}$$

$$\tau_c = \tau_{max}$$

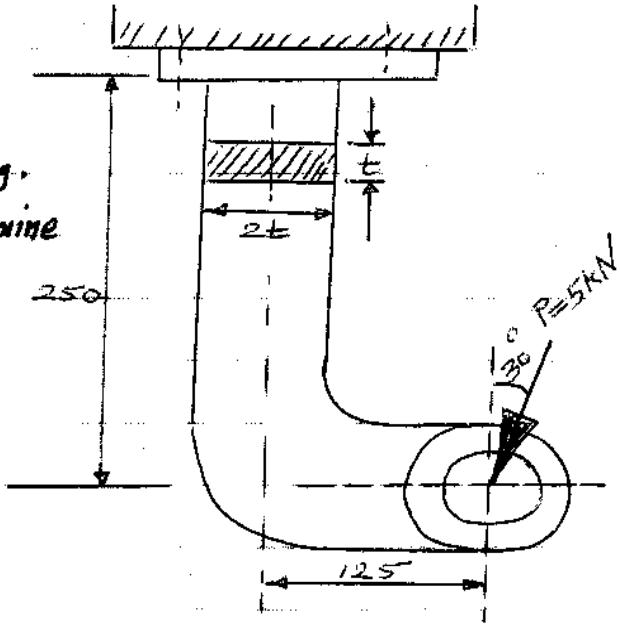
$$\tau_c = \frac{F\cdot A\cdot \bar{y}}{I\cdot b} = \frac{50*10^3*1575*39.6}{5.91*10^6*15} = 35.3 \text{ MPa}$$

$$\tau_{max} = F/A = \frac{50*10^3}{2(60*15)+(90*15)} = \frac{50*10^3}{3150} = 15.87 \text{ MPa}$$

$$\therefore \text{Ratio} = \frac{\tau_{max}}{\tau_{mean}} = \frac{35.3}{15.87} = 2.22 \quad \text{ans.}$$

Ex: Quiz

A braket, made of steel FeE200 ($\sigma_{yt} = 200\ N/mm^2$) and subjected to a force of 5 kN acting at angle of 30° to the vertical as shown in fig. The factor of safety is 4. Determine the dimensions of the cross-section of the braket.



Solution:

$\sigma_y = 200\ N/mm^2$, F.S = 4

$A = 2t * t = 2t^2\ mm^2$

$F_H = 5000 \sin 30 = 2500\ N$

$F_V = 5000 \cos 30 = 4330\ N$

$M_H = F_H * 250 = 2500 * 250 = 625000\ N.mm$

$M_V = F_V * 125 = 4330 * 125 = 541250\ N.mm$

$$\sigma_{oV} = \frac{F_V}{A} = \frac{4330}{2t^2} = \frac{2165}{t^2}$$

$$\sigma_{bH} = \frac{M_H \cdot \bar{y}}{I} = \frac{625000}{\frac{2t * t^3}{12}} * \frac{t}{2} = \frac{1875000}{t^3}$$

$$\sigma_{bV} = \frac{M_V \cdot \bar{y}}{I} = \frac{541250}{\frac{2t * t^3}{12}} * \frac{t}{2} = \frac{1623750}{t^3}$$

$$\frac{\sigma_y}{F.S} = \sigma_{oV} + \sigma_{bH} + \sigma_{bV}$$

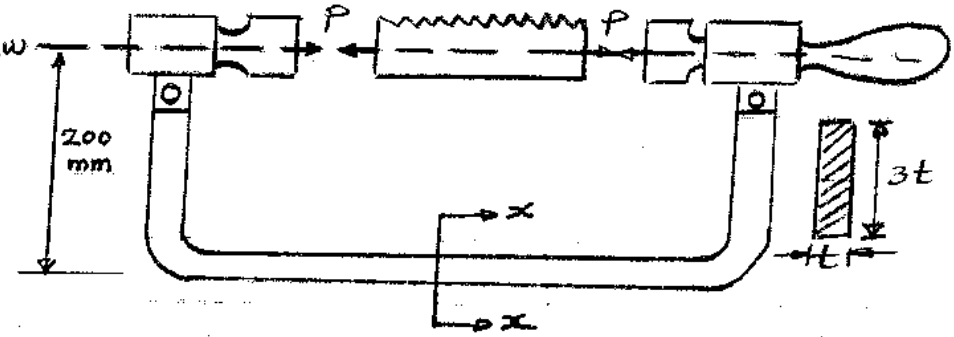
$$\frac{200}{4} = \frac{2165}{t^2} + \frac{1875000}{t^3} + \frac{1623750}{t^3}$$

By solving the final equation mathmatically (hit and trail)

$t =$ mm

Ex: Quiz

The frame of a hacksaw shown in fig., the initial tension (P) in the blade should be (300N), the frame is made of plain carbon steel 30C8 with tensile yield strength of 400 N/mm^2 and the factor of safety is 2.5, the cross-section of the frame is rectangular with a ratio of depth to width as 3. Determine the dimensions of the cross-section.



Solution

$A = 3t^2$, $\sigma_o = P/A = 300/3t^2 = 100/t^2$

$\sigma_b = M/Z = (300*200)/[\,t(3t)^2/6\,] = 4*10^4/t^3$

$\sigma_{total} = \sigma_o + \sigma_b = 100/t^2 + 4*10^4/t^3 = \frac{400}{2.5} = 160$

$t = 6.3$ mm

——x——x——x——x——x——x——x——

Trail and Error Method

$At^3 - Bt - C = 0$

$t = u + v$

$$u = \sqrt[3]{-\frac{C}{2} + \sqrt{\frac{C^2}{4} + \frac{B^3}{27}}}$$

$$v = \sqrt{-\frac{C}{2} - \sqrt{\frac{C^2}{4} + \frac{B^3}{27}}}$$

Ex:

Estimate the minimum shaft diameter according to the maximum shear stress theory for a shaft loaded with bending moment of $M = 50$ N.m and a torque of 40 N.m, the material has a yield strength of 1100 MPa.

Solution:

$M = 50$ N.m, $T = 40$ N.m, $\sigma_y = 1100$ MPa

$\sigma_b = M/I \cdot y$, $y = d/2$, $I = \pi/64 \cdot d^4$

$$\sigma_b = \frac{M * 64}{\pi d^4} * \frac{d}{2} = \frac{32M}{\pi d^3} = \frac{32*50}{\pi d^3} = \frac{509.296}{d^3}$$

$$\tau = \frac{T}{J} \cdot r, \quad r = d/2, \quad J = \frac{\pi}{32} d^4$$

$$\tau = \frac{16T}{\pi d^3} = \frac{16*40}{\pi d^3} = \frac{203.716}{d^3}$$

For Maximum shear stress theory:

$$\tau_{max} = \sqrt{(\sigma_b)^2 + 4\tau^2}$$

$$= \sqrt{\left(\frac{509.296}{d^3}\right)^2 + 4\left(\frac{203.716}{d^3}\right)^2} = \frac{326.108}{d^3}$$

$$FS = \frac{\sigma_y}{2\tau_{max}} \qquad FS = 1 \text{ for minimum shaft dia.}$$

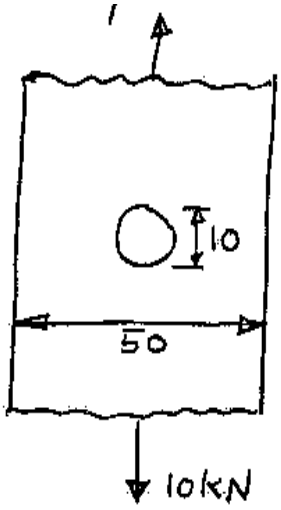
$$\sigma_y = 2\tau_{max} \Rightarrow 1100 * 10^6 = 2 * \frac{326.108}{d^3}$$

$$d = 8.4 \text{ mm} \simeq 8.5 \text{ mm}$$

Solutions of Problems - Chapter 6

1- Given: $b = 50$ mm , $h = 10$ mm , $d = 10$ mm

$P = 10$ kN



$$\frac{d}{b} = \frac{10}{50} = 0.2$$

from table (6.1) we get: $kt = 2.5$

$$\sigma_{normal} = P/A = \frac{10 * 10^3}{50 * 10} = 20 \ N/mm^2$$

$$\sigma_{max} = \sigma_{normal} * kt = 20 * 2.5 = 50 \ MPa$$

2- Given: $D = 45$mm, $d = 30$mm, $r = 6$mm, $P = 10$kN

$D/d = 45/30 = 1.5$, $r/d = 6/30 = 0.2$

from table (6.3) we get: $kt = 1.56$

$$\sigma_o = P/A = 10 * 10^3 / (\pi/4 d^2) = \frac{10 * 10^3}{\frac{\pi}{4}(30)^2} = 14.154 \ MPa$$

$$\sigma_{max} = \sigma_o * kt = 14.154 * 1.56 = 22 \ MPa$$

5- $F_{mean} = \frac{F_{max} + F_{min}}{2} = \frac{10+(-5)}{2} = \frac{10-5}{2} = 2.5\ kN$

$F_{variable} = \frac{F_{max} - F_{min}}{2} = \frac{10-(-5)}{2} = \frac{15}{2} = 7.5\ kN$

$\sigma_m = \frac{F_m}{A} = \frac{2.5*10^3}{\frac{\pi}{4}(d)^2} = \frac{10*10^3}{\pi d^2}$

$\sigma_v = \frac{F_v}{A} = \frac{7.5*10^3}{\frac{\pi}{4}(d)^2} = \frac{30*10^3}{\pi d^2}$

choose factors :

$q=1$, $K_f = K_t = 2.2$,

from fig. 6.3 according to $\sigma_u = 600$ MPa we get :

$K_{sur} = 0.75$, $K_a = 0.8$, $K_{sz} = 0.85$ for $d < 50$ mm

Then : By using sorderberg Method :

$$\frac{1}{F.S} = \frac{\sigma_m}{\sigma_y} + \frac{\sigma_v * K_f}{\sigma_e * K_a * K_b * K_{sur} * K_{sz} * K_i}$$

$$\frac{1}{4} = \frac{\frac{10*10^3}{\pi d^2}}{380} + \frac{\frac{30*10^3}{\pi d^2} * 2.2}{290*0.8*1*0.75*0.85*1}$$

$d = 24.53$ mm ans.

— x — x — x — x — x — x — x — x — x — x —

6 - $F_{max} = 25\ kN$, $F_{min} = -15\ kN$, $K_{sur} = 0.88$, $K_f = 2.25$

$\sigma_e = 360$ MPa , $\sigma_y = 400$ MPa, $K_i = 0.25$, $F.S = 1.5$

Assume $K_{sz} = 0.89$

$F_m = \frac{F_{max} + F_{min}}{2} = \frac{25-15}{2} = 5\ kN$, $\sigma_m = \frac{F_m}{A} = \frac{5*10^3*4}{\pi d^2} = \frac{20*10^3}{\pi d^2}$

$F_v = \frac{F_{max} - F_{min}}{2} = \frac{25+15}{2} = 20\ kN$, $\sigma_v = \frac{F_v}{A} = \frac{20*10^3*4}{\pi d^2} = \frac{80*10^3}{\pi d^2}$

By using Sorderberg Method;

$$\frac{1}{FS} = \frac{\sigma_m}{\sigma_y} + \frac{\sigma_v * K_f}{\sigma_e * K_i * K_{sz} * K_{sur}}$$

$$\frac{1}{1.5} = \frac{\frac{20*10^3}{\pi d^2}}{400} + \frac{\frac{80*10^3}{\pi d^2}}{360*0.25*0.88*0.89}$$

$d = 35.25 \simeq 35.3$ mm ans. (23)

7-

$F_{max} = 160\ kN$, $F_{min} = -160\ kN$ since the load is axial completely reversed

so $F_{mean} = 0$ then $\sigma_m = 0$

Assume $k_a = 0.8$, $\sigma_e = 0.5\,\sigma_u = 0.5 * 1100 = 550\ MPa$

$$F_v = \frac{160-(-160)}{2} = \frac{320}{2} = 160\ kN$$

$$\sigma_v = \frac{F_v}{A} = \frac{160*10^3}{\frac{\pi}{4}(d)^2} = \frac{640*10^3}{\pi d^2}$$

By using Sorderberg Method;

$$\frac{1}{FS} = \frac{\sigma_m}{\sigma_y} + \frac{\sigma_v * k_f}{\sigma_e * k_a * k_{sz} * k_{sur} * k_i}$$

$$\frac{1}{2} = \frac{0}{930} + \frac{\frac{640*10^3}{\pi d^2} * 1}{550 * 0.8 * 1 * 1 * 1}$$

$d = 30.43\ mm$ ans)

— x — x — x — x — x — x — x — x — x —

8- $F_{max} = 200\ kN$, $F_{min} = -200\ kN$ since the load is axial completely reversed

So $F_{mean} = 0$ then $\sigma_m = 0$, $\sigma_y = 440\ MPa$, $\sigma_u = 600\ MPa$

$k_{sur} = 0.8$, $FS = 1.5$, $k_a = 0.8$, $k_f = 1$, $k_{sz} = 0.75$

$\sigma_e = 0.5\,\sigma_u = 0.5 * 600 = 300\ MPa$, $F_v = \frac{200+200}{2} = 200\ kN$, $\sigma_v = \frac{800*10^3}{\pi d^2}$

By using Sorderberg Method:

$$\frac{1}{FS} = \frac{\sigma_m}{\sigma_y} + \frac{\sigma_v * k_f}{\sigma_e * k_a * k_{sur} * k_{sz} * k_b}$$

$$\frac{1}{1.5} = \frac{0}{440} + \frac{\frac{800*10^3}{\pi d^2} * 1}{300 * 0.8 * 0.8 * 0.75 * 1}$$

$d = 51.5\ mm$ ans)

9- Given: $T_{max} = 1600\ N.m$, $T_{min} = 800\ N.m$

$\sigma_u = 600\ MPa$, $\sigma_y = 450\ MPa$, $k_{fs} = 1.2$, $k_{sur} = 0.8$, $k_{sz} = 0.85$

Let $FS = 1$, $\sigma_e = 0.5\,\sigma_u = 0.5 * 600 = 300\ MPa$

$\tau_e = 0.55\,\sigma_e = 0.55 * 300 = 165\ MPa$

$\tau_y = 0.5\,\sigma_y = 0.5 * 450 = 225\ MPa$

$T_m = \frac{1600+800}{2} = 1200*10^3\ N.mm$, $T_v = \frac{1600-800}{2} = 400*10^3\ N.mm$

$\tau_m = \frac{T_m}{J}.r = \frac{1200*10^3*16}{\pi d^3}$, $\tau_v = \frac{T_v}{J}.r = \frac{400*10^3*16}{\pi d^3}$

According to Sorderberg's formula:

$$\frac{1}{FS} = \frac{\tau_m}{\tau_y} + \frac{\tau_v * k_{fs}}{\tau_e * k_{sur} * k_{sz}}$$

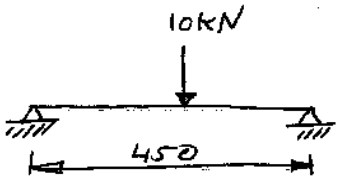
$$\frac{1}{1} = \frac{\frac{1200*10^3*16}{\pi d^3}}{225} + \frac{\frac{400*10^3*16}{\pi d^3} * 1.2}{165 * 0.8 * 0.85}$$

$d = 36.58\ mm$ ans)

— x — x — x — x — x — x — x — x —

10- Given: $\sigma_e = 800\ MPa$, $k_{sur} = 0.87$, $k_{sz} = 0.85$

$FS = 1.6$, $F_{max} = 10\ kN$, $F_{min} = -10\ kN$, $k_f = 1$



$M_v = \frac{W.l}{4} = \frac{10*450*10^3}{4} = 1125*10^3\ N.mm$

$Z = \frac{\pi}{32} d^3$

$\sigma_v = \frac{M_v}{Z} = \frac{1125*10^3}{\frac{\pi}{32} d^3} = \frac{36*10^6}{\pi d^3}$

Steady load $\sigma_m = 0$

By using Sorderberg's formula;

$$\frac{1}{FS} = \frac{\sigma_m}{\sigma_y} + \frac{\sigma_v * k_f}{\sigma_e * k_{sur} * k_{sz}}$$

$$\frac{1}{1.6} = \frac{0}{\sigma_y} + \frac{\frac{36*10^6}{\pi d^3} * 1}{600 * 0.87 * 0.85}$$

$d = 34.57 \simeq 35\ mm$ ans)

(25)

11- $\sigma_e = 280\ MPa$, $\sigma_y = 350\ MPa$, $kt = 1.8$, $FS = 2$

$F_{max} = 700\ kN$, $F_{min} = -300\ kN$

Let $q = 0$, So $k_f = 1 + q(k_t - 1) = 1$

$$F_m = \frac{F_{max} + F_{min}}{2} = \frac{700 + (-300)}{2} = 200\ kN$$

$$F_v = \frac{F_{max} - F_{min}}{2} = \frac{700 - (-300)}{2} = 500\ kN$$

$$\sigma_m = \frac{F_m}{A} = \frac{200 * 10^3}{\frac{\pi}{4} d^2} = \frac{800 * 10^3}{\pi d^2}$$

$$\sigma_v = \frac{F_v}{A} = \frac{500 * 10^3}{\frac{\pi}{4} d^2} = \frac{2000 * 10^3}{\pi d^2}$$

By using Sorderberg's formula ;

$$\frac{1}{FS} = \frac{\sigma_m}{\sigma_y} + \frac{\sigma_v * k_f}{\sigma_e * k_a * k_b * k_{sur} * k_{sz}}$$

$$\frac{1}{2} = \frac{\frac{800 * 10^3}{\pi d^2}}{350} + \frac{\frac{2000 * 10^3}{\pi d^2} * 1}{280 * 1 * 1 * 1 * 1}$$

$$d = 77.49 \simeq 80\ mm$$

12- Given: Cold drawn steel rod

$F_{b\,max} = 1130$, $F_{b\,min} = 565$, $F_{a\,max} = 13500N$, $F_{a\,min} = 4500N$

$k_{sz} = 0.85$, $k_{sur} = 0.89$, $k_b = 1$, $k_a = 0.7$, $k_f = 1$, $F.S = 2$

$\sigma_u = 550MPa$, $\sigma_y = 470MPa$, $\sigma_e = 0.5\sigma_u = 0.5*550 = 275MPa$

Solution : For bending Load:

$$M_m = \frac{M_{max}+M_{min}}{2} = \frac{1130+565}{2} = 847.5*10^3 \ N.mm$$

$$M_v = \frac{M_{max}-M_{min}}{2} = \frac{1130-565}{2} = 282.5*10^3 \ N.mm$$

$$\sigma_{mb} = \frac{M_m}{Z} = \frac{847.5*10^3*32}{\pi d^3} \ , \sigma_{mv} = \frac{M_v}{Z} = \frac{282.5*10^3*32}{\pi d^3}$$

$$\sigma_{ne_b} = \sigma_m + \frac{\sigma_v * \sigma_y * k_f}{\sigma_e * k_b * k_{sur} * k_{sz}}$$

$$= \frac{847.5*10^3*32}{\pi d^3} + \frac{\frac{282.5*10^3*32}{\pi d^3} * 470 * 1}{275*1*0.89*0.85} = \frac{15133.48*10^3}{d^3}$$

For axial Load:

$$F_m = \frac{F_{max}+F_{min}}{2} = \frac{13500+4500}{2} = 9000 \ N$$

$$F_v = \frac{F_{max}-F_{min}}{2} = \frac{13500-4500}{2} = 4500 \ N$$

$$\sigma_m = \frac{F_m}{A} = \frac{9000*4}{\pi d^2} \ , \sigma_v = \frac{F_v}{A} = \frac{4500*4}{\pi d^2}$$

$$\sigma_{ne_a} = \sigma_m + \frac{\sigma_v * \sigma_y * k_f}{\sigma_e * k_a * k_b * k_{sur} * k_{sz}}$$

$$= \frac{9000*4}{\pi d^2} + \frac{\frac{4500*4}{\pi d^2} * 470 * 1}{275*0.7*1*0.89*0.85} = \frac{29951}{d^2}$$

$\sigma_{max} = \sigma_y / F.S$

$$\sigma_{max} = \sigma_{ne} = \sigma_{ne_b} + \sigma_{ne_a} = \frac{15133.48*10^3}{d^3} + \frac{29951}{d^2} = \frac{470}{2}$$

By using hit and trail:

$d = 40.5 \simeq 41 \ mm$

13- Given: $\sigma_u = 550\ MPa$, $\sigma_y = 470\ MPa$, $F.S = 2$, $k_{fb} = 1.44$, $k_{sz} = 0.85$

$\sigma_e = 275\ MPa$, $k_{fa} = 1.63$

For axial Load:

$$w_m = \frac{w_{max} + w_{min}}{2} = \frac{450 + (-110)}{2} = 170N$$

$$w_v = \frac{w_{max} - w_{min}}{2} = \frac{450 - (-110)}{2} = 280N$$

$$\sigma_m = \frac{w_m}{A} = \frac{170 * 4}{\pi d^2} = \frac{680}{\pi d^2}, \quad \sigma_v = \frac{w_v}{A} = \frac{280 * 4}{\pi d^2} = \frac{1120}{\pi d^2}$$

$$\sigma_{nea} = \sigma_m + \frac{\sigma_v * \sigma_y * k_{fa}}{\sigma_e * k_a \cdot k_b \cdot k_{sur} \cdot k_{sz}}$$

$$= \frac{680}{\pi d^2} + \frac{\frac{1120}{\pi d^2} * 470 * 1.63}{275 * 1 * 1 * 0.9 * 0.85} = \frac{1515.472}{d^2}$$

For bending Load:

$$w_m = \frac{w_{max} + w_{min}}{2} = \frac{135 + 45}{2} = 90N, \quad M_m = 90 * 125 = 11250\ N.mm$$

$$w_v = \frac{w_{max} - w_{min}}{2} = \frac{135 - 45}{2} = 45N, \quad M_v = 45 * 125 = 5625\ N.mm$$

$$Z = \frac{\pi}{32} d^3,$$

$$\sigma_{mb} = \frac{M_m}{Z} = \frac{11250 * 32}{\pi d^3} = \frac{114649.68}{d^3}$$

$$\sigma_{vb} = \frac{M_v}{Z} = \frac{5625 * 32}{\pi d^3} = \frac{57324.841}{d^3}$$

$$\sigma_{neb} = \sigma_{mb} + \frac{\sigma_v * \sigma_y * k_{fb}}{\sigma_e * k_a * k_b * k_{sur} * k_{sz}}$$

$$= \frac{114649.68}{d^3} + \frac{\frac{57324.841}{d^3} * 470 * 1.44}{275 * 1 * 0.9 * 0.85} = \frac{299070.13}{d^3}$$

$$\sigma_{ne} = \sigma_{nea} + \sigma_{neb} = \sigma_{max} = \frac{\sigma_y}{FS}$$

$$\frac{1515.472}{d^2} + \frac{299070.13}{d^3} = \frac{470}{2}$$

By hit and trail:

$d = 11.035 \simeq 11.5$ ans)

14- Given: $M_v = 800\ N.m$, $T = 500\ N.m$, $\mp 40\%$, $k_{fs} = 1.2$, $\sigma_y = 500\ MPa$

$\sigma_u = 800\ MPa$, $\sigma_e = 400\ MPa$.

$\tau_y = 0.5\,\sigma_y = 0.5 * 500 = 250\ MPa$

$T_{max} = T + (T * 40\%) = 500 + (500 * \frac{40}{100}) = 700\ N.m$

$T_{min} = T - (T * 40\%) = 500 - (500 * \frac{40}{100}) = 300\ N.m$

$T_m = \frac{T_{max} + T_{min}}{2} = \frac{700+300}{2} = 500\ N.m$

$T_v = \frac{T_{max} - T_{min}}{2} = \frac{700-300}{2} = 200\ N.m$

$\tau_m = \frac{16 T_m}{\pi d^3} = \frac{16 * 500 * 10^3}{\pi d^3} = \frac{8 * 10^6}{\pi d^3}$

$\tau_v = \frac{16 T_v}{\pi d^3} = \frac{16 * 200 * 10^3}{\pi d^3} = \frac{3.2 * 10^6}{\pi d^3}$

$\tau_{ne_s} = \tau_m + \frac{\tau_v * \tau_y * k_{fs}}{\tau_e * k_{sz} * k_{sur}} = \frac{8 * 10^6}{\pi d^3} + \frac{\frac{3.2 * 10^6}{\pi d^3} * 250 * 1.2}{400 * 0.55} = \frac{3.937 * 10^6}{d^3}$

$\sigma_m = 0$

$\sigma_{ne_b} = \sigma_m + \frac{\sigma_v * \sigma_y * k_f}{\sigma_e} = 0 + \frac{800 * 10^3 * 32 * 500}{400} =$

$= 0 + \frac{\frac{8 * 10^3}{\pi d^3} * 500 * 1.2}{400} = \frac{3.8217 * 10^6}{d^3}$

According to Max. shear stress theory:

$$\frac{250}{F.S} = \frac{1}{2} \sqrt{(\sigma_t)^2 + 4\tau^2}$$

$$\frac{250}{1.2} = \frac{1}{2} \sqrt{\left(\frac{3.8217 * 10^6}{d^3}\right)^2 + 4\left(\frac{3.937 * 10^6}{d^3}\right)^2}$$

By solving the final equation mathmatically:

$d = 40.8 \simeq 41\ mm$ ans

15-

$T_{max}=165$, $T_{min}=55$, $M_{max}=510$, $M_{min}=-170$, $\sigma_u=540\,MPa$

$\sigma_y=400\,MPa$, $k_{fb}=1.6$, $k_{fs}=1.3$, $F.S=1.5$, $k_{sz}=0.85$, $k_{sur}=0.88$

$$M_m=\frac{M_{max}+M_{min}}{2}=\frac{510+(-170)}{2}=170\ N.m$$

$$M_v=\frac{M_{max}-M_{min}}{2}=\frac{510-(-170)}{2}=340\ N.m$$

$$Z=\frac{\pi}{32}d^3=0.0982\,d^3,\quad \sigma_m=M_m/Z=170/0.0982d^3=1731.16/d^3$$

$$\sigma_v=M_v/Z=340/0.0982d^3=3462.321/d^3$$

Assume that $\sigma_e=0.5\,\sigma_u=540*0.5=270\ N/m^2$

$$\sigma_{eb}=\sigma_e=\frac{\sigma_y}{2}=\frac{540}{2}=270$$

$$\sigma_{neb}=\sigma_{ne}=\sigma_m+\frac{\sigma_v*\sigma_y*k_{fb}}{\sigma_{eb}*k_{sur}*k_{sz}}$$

$$=\frac{1731.16}{d^3}+\frac{\frac{3462.322}{d^3}*400*1.6}{270*0.88*0.85}=\frac{12703.066}{d^3}$$

$$T_m=\frac{T_{max}+T_{min}}{2}=\frac{165+55}{2}=110\ N.m$$

$$T_v=\frac{T_{max}-T_{min}}{2}=\frac{165-55}{2}=55\ N.m$$

$$\tau_m=16T_m/\pi d^3=16*110/\pi d^3=560.509/d^3$$

$$\tau_v=16T_v/\pi d^3=16*55/\pi d^3=280.254/d^3$$

$$\tau_e=0.55\,\sigma_e=0.55*270=148.5$$

$$\tau_y=0.5\,\sigma_y=0.5*400=200$$

$$\tau_{es}=\tau_m+\frac{\tau_v*\tau_y*k_{fs}}{\tau_e*k_{sur}*k_{sz}}$$

$$=\frac{590.509}{d^3}+\frac{\frac{280.254}{d^3}*200*1.3}{148.5*0.88*0.85}=\frac{1216.498}{d^3}$$

$$\tau_{es(max)}=\frac{\tau_y}{F.S}=\frac{1}{2}\sqrt{(\sigma_{ne})^2+4(\tau_{es})^2}$$

$$\frac{400}{1.5}=\frac{1}{2}\sqrt{\left(\frac{12703.066}{d^3}\right)^2+4\left(\frac{1216.498}{d^3}\right)^2}$$

$d=35.8\ mm\simeq 36.5$ ans

Solutions of ch. 10

1-

For static load

$P = 0.707 * S * l * \sigma_t = 2 * 0.707 * 10 * l * 70 \Rightarrow l = 70.72$

$L_{Total} = 70.72 + 12.5 = 83.2$ mm ans.

For Fatigue load

$K_w = 1.5$ From table 10.6

$\sigma_t = 70/1.5$

$\therefore P = 2 * 0.707 * 10 * l * \frac{70}{1.5}$

$70 * 10^3 = 2 * 0.707 * 10 * l * 70/1.5 \Rightarrow l = 106.8$ mm

$L_{Total} = 106.8 + 12.5 = 118.58$

2-

For static load

$P = 2 * 0.707 * S * l * \tau$

$70 * 10^3 = 2 * 0.707 * 10 * l * 56 \Rightarrow l = 88.4$ mm

$L_{Total} = 88.4 + 12.5 = 100.9$ mm

For Fatigue load

$K_w = 2.7$ (for parallel – from table 10.6)

$\tau = 56/2.7$

$P = 2 * 0.707 * S * l * \tau$

$70 * 10^3 = 2 * 0.707 * 10 * l * 56/2.7 \Rightarrow l = 238.68$ mm

adding 12.5 mm for starting and stopping weld run

$L_{Total} = 238.68 + 12.5 = 251.2$ mm

3- $L = \frac{\text{Tensile load}}{\text{load per mm}} = \frac{180 * 10^3}{430} = 418.6 \text{ mm}$

$b = \bar{y} = \frac{\sum A_i y_i}{\sum A_i} = \frac{85*10*5 + 125*10*62.5}{125*10 + 85*10} = 39.226 \text{ mm}$

$d = 125 - 39.226 = 85.774 \text{ mm}$ $(a+b = 125)$

$L_a = \frac{L*b}{a+b} = \frac{418.6 * 39.226}{125} = 131.36 \text{ mm}$

$L_b = \frac{L*a}{a+b} = \frac{418.6 * 85.774}{125} = 287.24 \text{ mm}$

checking :

$L_a + L_b = 131.36 + 287.24 = 418.6 \text{ mm}$

Note : The edges of 125 mm leg instead of 150 mm leg.

— x — x — x — x — x — x — x — x —

4-

$M = P * l = 5 * 10^3 * 200 = 1000 * 10^3 \text{ N.mm}$

$\sigma_{b\max} = \frac{5.66M}{\pi . S . d^2}$

$100 = \frac{5.66 * 1000 * 10^3}{\pi * S * (50)^2} \Rightarrow S = 72 \text{ mm}$ ans

— x — x — x — x — x — x — x — x — x —

5- $T = 3 \text{kN.m} = 3 * 10^3 * 10^3 = 3 * 10^6 \text{ N.mm}$

$\tau_{max} = \frac{2.83\,T}{\pi . S . d^2}$

$70 = \frac{2.83 * 3 * 10^6}{\pi * S * (65)^2} \Rightarrow S = 9.13 \text{ mm} \simeq 10 \text{ mm}$

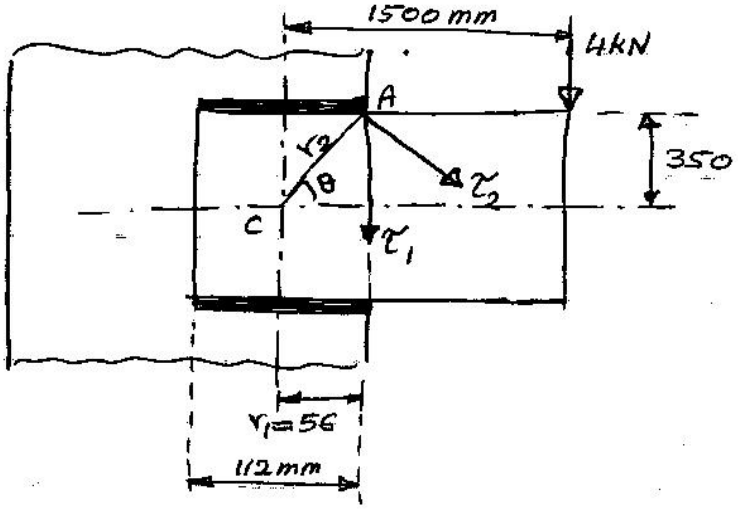
if $d = 62 \text{ mm}$ then $S = 10 \text{ mm}$ ans

— x — x — x — x — x — x — x — x — x — x —

6- $\tau_{max} = \frac{4.242\,T}{S . L^2} * 2$ for four sides

$85 = \frac{4.242 . T}{5(8)^2} * 2 \Rightarrow T = 320.603 \text{ N.m} = 32.06 \text{ kN.m}$

7-



$$r_2 = \sqrt{(56)^2 + (350)^2} = 354.45 mm$$

$$J = \frac{t \cdot L \cdot (3b^2 + L^2)}{6}$$

$$= \frac{t * 112 [3(700)^2 + (112)^2]}{6}$$

$$= 27674154.66\, t$$

$$\tau_1 = P/A = \frac{4 * 10^3}{112 * 2 * t} = \frac{17.857}{t} \quad MPa$$

$$\tau_2 = \frac{P \cdot e \cdot r_2}{J} = \frac{4 * 10^3 + 1500 * 354.45}{27674154.66\, t} = \frac{76.85}{t} \quad MPa$$

$$\cos\theta = \frac{r_1}{r_2} = \frac{56}{354.452} = 0.158$$

$$\tau = \frac{1}{t} \left[(17.857)^2 + (76.85)^2 + 2 * 17.857 * 76.85 * 0.158 \right]^{1/2}$$

$$= \frac{81.6}{t} = \tau_{weld} = 60 \Rightarrow t = 1.36 \Rightarrow s = \frac{1.36}{0.707} = 1.923 mm$$

∴ thickness = 1.923 ≃ 2 mm ans.

checking for plate:

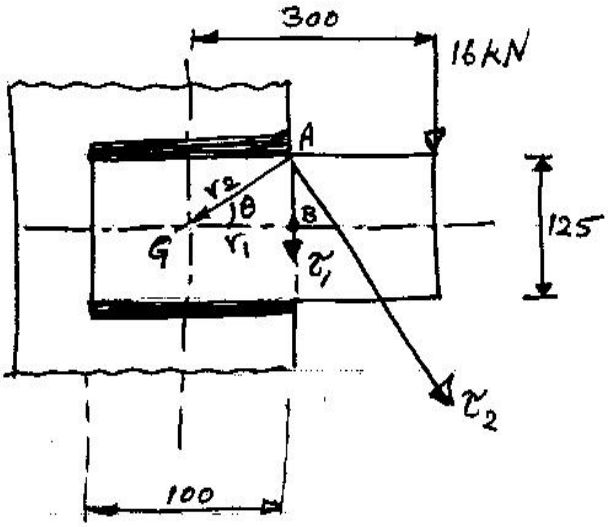
$$\sigma_b = \frac{M}{I} \cdot y = \frac{4000 * 1500}{\frac{2 * (700)^3}{12}} * \frac{700}{2} = 36.73 MPa$$

$$\tau = P/A = 4 * 10^3 / 700 * 2 = 2.86 MPa$$

$$\tau_{max} = \frac{1}{2} \sqrt{(36.73)^2 + 4(2.86)^2} = 18.58 MPa$$

Since $\tau_{max} < 40 MPa$ (allowable stress of the plate) Then our design in the safe region.

8-



$$r_2 = \sqrt{(r_1)^2 + (AB)^2}$$

$$= \sqrt{(50)^2 + (62.5)^2}$$

$$= 80.04 \text{ mm}$$

$$J = \frac{t \cdot L\,(3b^2 + L^2)}{6}$$

$$= \frac{0.707 * 10 * 100\,[3(125)^2 + (100)^2}{6}$$

$$= 6701770.833 \text{ mm}^4$$

Secondary shear stress:

$$\tau_2 = \frac{P \cdot e \cdot r_2}{J} = \frac{16*10^3 * 300 * 80.04}{6701770.833} = 57.33 \text{ MPa}$$

Direct shear stress:

$$\tau_1 = P/A = \frac{16*10^3}{2.*0.707*10*100} = 11.315 \text{ MPa}$$

$$\cos\theta = r_1/r_2 = 50/80.04 = 0.6246$$

$$\tau = [\tau_1^2 + \tau_2^2 + 2\tau_1\tau_2\cos\theta]^{1/2}$$

$$= [(11.315)^2 + (57.33)^2 + 2*11.315*57.33*0.6246]^{1/2}$$

$$= 65 \text{ MPa}$$

if $t = 10$ mm then $\tau = 45.9$ MPa

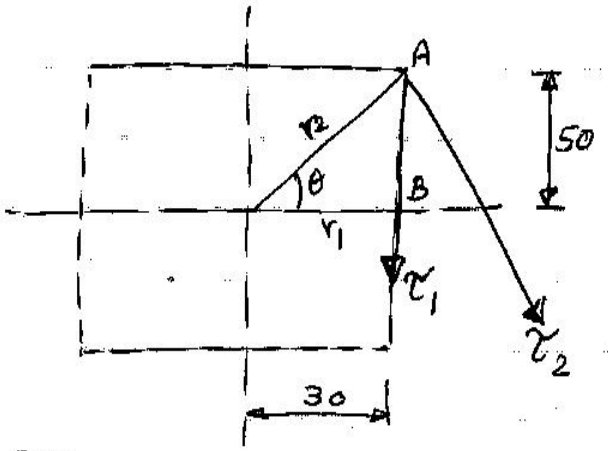
9-

$$J = \frac{t*L\,[3b^2+L^2]}{6} = \frac{t*60\,[3(100)^2+(60)^2]}{6} = 336000t \text{ mm}^4$$

$$r_2 = \sqrt{(r_1)^2+(AB)^2}$$

$$= [(30)^2+(50)^2]^{1/2}$$

$$= 58.31 \text{ mm}$$



$$\cos\theta = r_1/r_2 = 30/58.31$$

$$= 0.514$$

Primary (direct) shear stress

$$\tau = P/A = \frac{10*10^3}{2*t*60} = \frac{83.333}{t} \text{ MPa}$$

Secondary shear stress:

$$\tau_2 = \frac{P.e.r_2}{J} = \frac{10*10^3*150*58.31}{336000\,t} = \frac{260.3}{t} \text{ MPa}$$

$$\tau_{max} = [\tau_1^2+\tau_2^2+2\tau_1\tau_2\cos\theta]^{1/2}$$

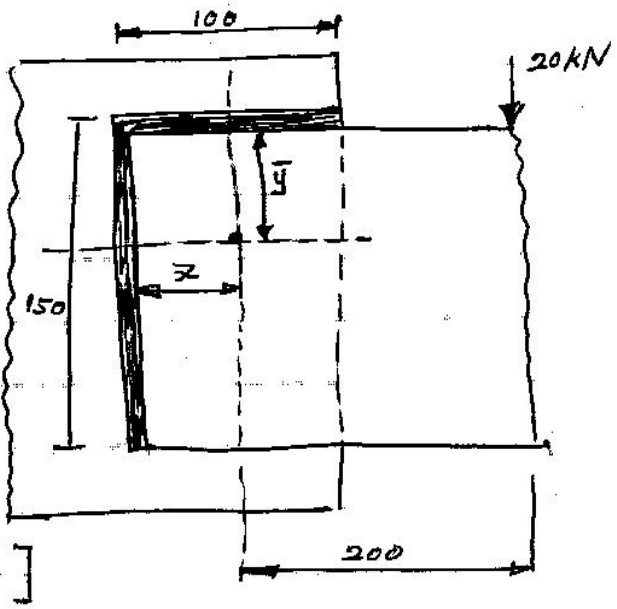
$$= \left[\left(\frac{83.33}{t}\right)^2+\left(\frac{260.3}{t}\right)^2+2*\frac{83.33}{t}*\frac{260.3}{t}*0.514\right]^{1/2}$$

$$80 = \frac{1}{t}*311.46$$

$$t = 3.893 \text{ mm}$$

$$S = \frac{t}{0.707} = \frac{3.893}{0.707} = 5.51 \text{ mm}$$

10-



$$\bar{x} = \frac{L^2}{2(L+b)} = \frac{(100)^2}{2(100+150)}$$

$$= 20\ mm$$

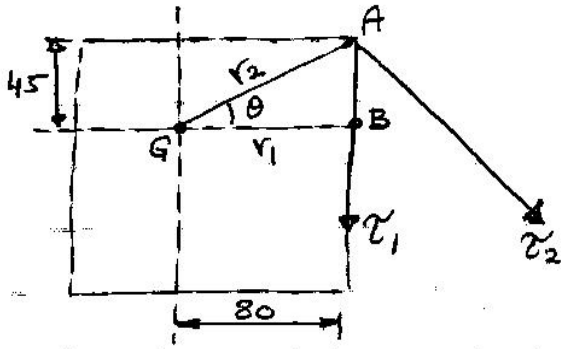
$$\bar{y} = \frac{b^2}{2(L+b)} = \frac{(150)^2}{2(100+150)}$$

$$= 45\ mm$$

$$J = t\left[\frac{(b+t)^4 - 6*b^2*L^2}{12(L+b)}\right]$$

$$= 0.707S\left[\frac{(150+100)^4 - 6(150)^2(100)^2}{12(100+150)}\right]$$

$$= 602422.916S$$



$$r_2 = \sqrt{(r_1)^2 + (AB)^2}$$

$$= \left[(100-20)^2 + (45)^2\right]^{1/2}$$

$$= 91.788\ mm$$

$$\cos\theta = r_1/r_2 = 80/91.788 = 0.87$$

Primary (direct) shear stress

$$\tau_1 = P/A = 20*10^3 / (100*0.707S + 150*0.707S) = \frac{113.154}{S}\ MPa$$

Secondary shear stress

$$\tau_2 = \frac{P.e.r_2}{J} = \frac{20*10^3*200*91.788}{602422.916S} = \frac{609.46}{S}\ MPa$$

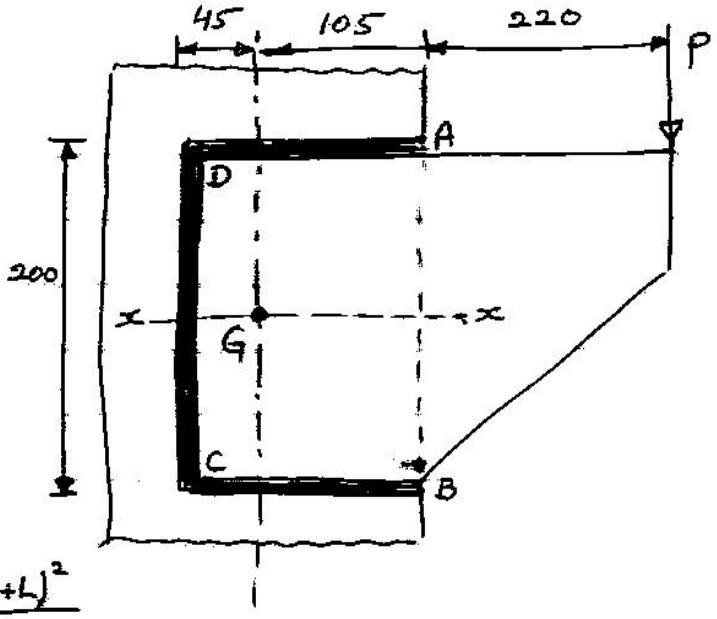
$$\tau_{max} = \left[\tau_1^2 + \tau_2^2 + 2\tau_1\tau_2\cos\theta\right]^{1/2}$$

$$= \left[\left(\frac{113.154}{S}\right)^2 + \left(\frac{609.46}{S}\right)^2 + 2*\frac{113.154}{S}*\frac{609.46}{S}*0.87\right]^{1/2}$$

$$= \frac{710}{S}\ MPa$$

$$80 = \frac{710}{S} \Rightarrow S = 8.875 \simeq 8.9\ mm \quad \text{ans}$$

11-



$$x = \frac{L^2}{2L+b}$$

$$= \frac{(150)^2}{2*150+200}$$

$$= 45$$

$$r_2 = [(150-45)^2 + (100)^2]^{1/2}$$

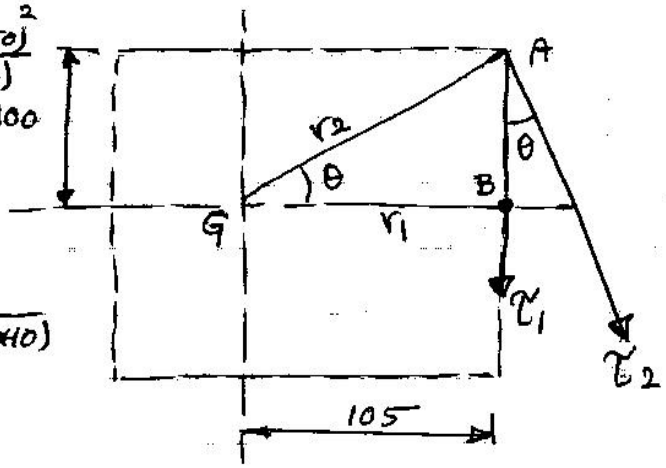
$$= 145 \text{ mm}$$

$$J = t\left[\frac{(b+2L)^3}{12} - \frac{(L^2(b+L)^2}{b+2L}\right.$$

$\cos\theta = r_1/r_2 = 105/145 = 0.724$

$$= 0.707*10\left[\frac{(200+2(150))^3}{12} - \frac{(150)^2(200+150)^2}{200+2(150)}\right.$$

$$= 34672458.32 \text{ mm}^4$$



Primary (direct) shear stress:

$$\tau_1 = P/A$$

$$= \frac{P}{(2*150*0.707*10)+(200*0.707*10)}$$

$$= 2.828*10^{-4} P \quad MPa$$

Secondary shear stress:

$$\tau_2 = \frac{P \cdot e \cdot r_2}{J}$$

$$= \frac{P*(220+105)*45}{34672458.32} = 13.6*10^{-4} P \quad MPa$$

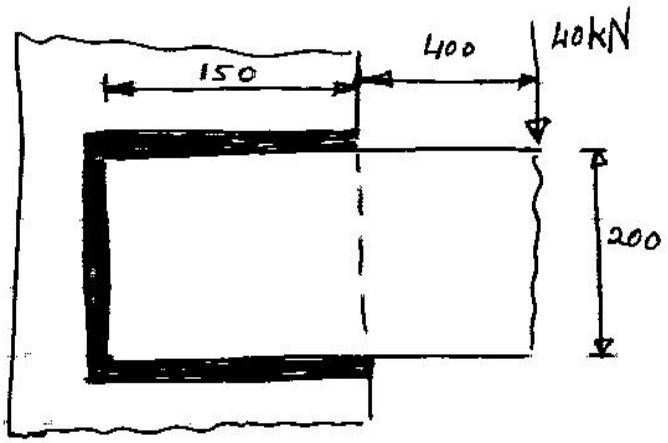
$$\tau_{max} = [(2.828*10^{-4}P)^2 + (13.6*10^{-4}P)^2 + 2*(2.828*10^{-4}P)(13.6*10^{-4}P)*0.724]^{1/2}$$

$$= 15.77*10^{-4} P$$

$$80 = 15.77*10^{-4} P$$

$$P = 50728.55 N = 50.728 \text{ kN} \quad \text{ans}$$

12-



$$x = \frac{L^2}{2L+b}$$

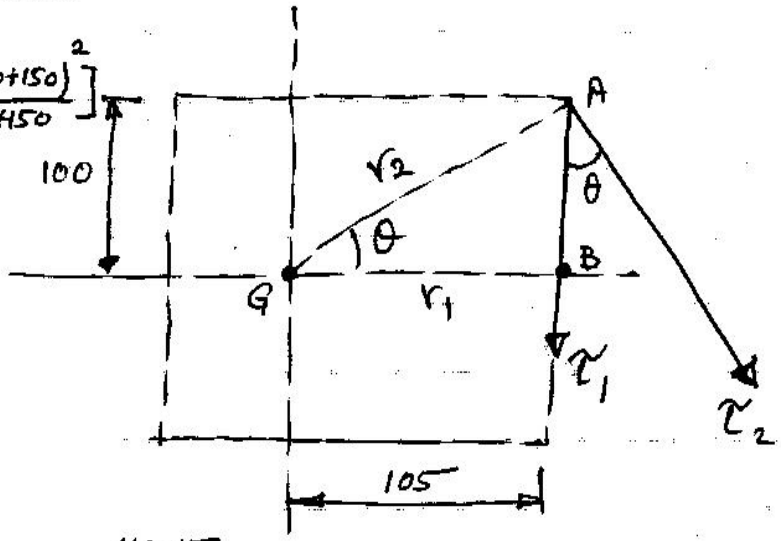
$$= \frac{(150)^2}{2*150+200}$$

$$= 45 \text{ mm}$$

$$J = 0.707S\left[\frac{(b+2L)^3}{12} - \frac{L^2(b+L)^2}{b+2L}\right]$$

$$= 0.707S\left[\frac{(200+300)^3}{12} - \frac{(150)^2(200+150)^2}{200+2*150}\right]$$

$$= 3467245.832(S)$$



$$r_2 = [(105)^2 + (100)^2]^{1/2}$$

$$= 145$$

$$\cos\theta = r_1/r_2 = 105/145 = 0.724$$

Direct stress of shear

$$\tau_1 = P/A$$

$$= \frac{40*10^3}{2*0.707S + 0.707S*200} = \frac{113.15}{S} \text{ MPa}$$

Secondary stress of shear

$$\tau_2 = \frac{P.e.r_2}{J} = \frac{40*10^3*400*145}{3467245.832S} = \frac{844.763}{S} \text{ MPa}$$

$$\tau_{max} = [\tau_1^2 + \tau_2^2 + 2\tau_1\tau_2\cos\theta]^{1/2}$$

$$= \left[\left(\frac{113.15}{S}\right)^2 + \left(\frac{844.763}{S}\right)^2 + 2*\frac{113.15}{S}*\frac{844.763}{S}*0.724\right]^{1/2}$$

$$= 929/S$$

$$80 = 929/S \Rightarrow S = 11.6 \text{ mm} \Rightarrow t = 8.2 \text{ mm}$$

if $e = 400$ then $S = 10$ mm $\Rightarrow t = 7.07$ mm

Solutions of ch.11 (Screw joints)

1-

From table 11.1 :

stress area for M20 = 245 mm^2 , and for M36 = 817 mm^2

$P = A * \sigma_t = 245 * 200 = 49000$ kN for M20

$= 817 * 200 = 163400 = 163.4$ kN for M36

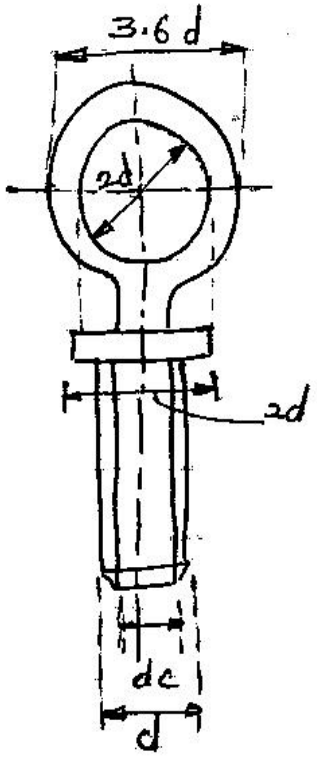
2- $P = \frac{\pi}{4}(d_c)^2 \cdot \sigma_t$

$20*10^3 = \frac{\pi}{4}(d_c)^2 * 100$

$d_c = 15.95$ mm

The nearest value of d_c from table 11.1

$d_c = 16.933$ mm , M20 ans.



3- $P = \frac{\pi}{4}(D)^2 \cdot p = \frac{\pi}{4}(300)^2 * 0.7 = 49480.1$ N

$P = \frac{\pi}{4} d_c^2 \cdot \sigma_t \cdot n$

$49480 = \frac{\pi}{4} d_c^2 * 28 * 12$

$d_c = 13.693$

The nearest standard value of d_c from table 11.1

$d_c = 14.933$, M = 18

4-

$$P = \frac{\pi}{4}(D)^2 \cdot p = \frac{\pi}{4} d_c^2 \cdot \sigma_t \cdot n$$

$$(400)^2 * 1.2 = d_c^2 * 35 * 14$$

$$d_c = 19.794$$

from table 11.1 we obtain standard value of d_c

$d_c = 20.32 \Rightarrow$ M24 ans)

5- $P = \frac{\pi}{4}(D)^2 \cdot p = \frac{\pi}{4}(300)^2 * 1 = 70685.835\ N$

External Load on each bolt:

$P_2 = P/n = 70685.835/12 = 5890.486\ N$

Tensile load, $P_i = 2840d$

From table 11.2 we obtain $k = 0.5$ for soft copper gasket

∴ Resultant axial load on the bolt:

$$P_{bolt} = P_i + k \cdot P_2 = 2840d + 0.5(5890.486)$$

$$P = \frac{\pi}{4} d_c^2 \cdot \sigma_t = \frac{\pi}{4}(d_c^2) * 100 \qquad (d_c = 0.84d)$$

$$P_{bolt} = P$$

$$2840d + 0.5(5890.486) = \frac{\pi}{4} d_c^2 * 100$$

$d = 52.26$, M56

6- $P = \frac{\pi}{4} D^2 \cdot p = \frac{\pi}{4}(300)^2 * 1.5 = 106028.75\ N$

$P_2 = P/n = 106028.75/8 = 13253.6\ N$

$P_1 = 2840d$, $P_{bolt} = P_i + k \cdot P_2 = 2840d + 0.5(13253.6)$

$$P_{bolt} = \frac{\pi}{4} d_c^2 * \sigma_t$$

$$2840d + 0.5(13253.6) = \frac{\pi}{4}(0.84d)^2 * \sigma_t$$

$d = 20$ mm according to M20 from table 11.1

∴ $\sigma_t = 286.13$ MPa

7- $P = \frac{\pi}{4} D^2 \cdot p = \frac{\pi}{4}(400)^2 * 1.12 = 140743.35\ N$

Assum that : M24 for studi $dc =$ (from table 11.1) $= 20.32\ mm$

The load effected on studs for (n) number of studs

$P = \frac{\pi}{4} d_c^2 * \sigma_t * n = \frac{\pi}{4}(20.32)^2 * 35 * n = 11350.25\ n$

$n = 140743.35 / 11350.25 = 12.4 \simeq 14$ (*)

Taking diamer of stud hole as $d_1 = d+1 = 24+1 = 25\ mm$

$Dp = D + 2t + 3d_1$ (Assume $t = 10\ mm$)

$= 400 + 2*10 + 3*25 = 495\ mm$

∴ circumferential Pitch of the studi

$= \frac{\pi Dp}{n} = \frac{\pi * 395}{14} = 111.1\ mm$

checking the design :

For leak proof joint, the value of circumferential Pitch of studs should be between $20\sqrt{d_1}$ and $30\sqrt{d_i}$

Min. circumferential Pitch $= 20\sqrt{d_i} = 20\sqrt{25} = 100\ mm$

Max. circumferential Pitch $= 30\sqrt{d_i} = 30\sqrt{25} = 150\ mm$

Since the value of circumferential Pitch (111.1mm) Lies between the the min. and max (100 and 150), then the size of studs which we choosen was correct and in safe (satisfactory)

∴ M24 , n = 14 ans)

(*) we choose the number of studs (14) as the nearest even number of (12.4)

even even

نختار أقرب اعلى رقم زوجي صحيح

8- Assume that:

$\sigma_t = 35$ MPa , $t = 10$ mm , M24 for studs

from table 11.1, $d_c = 20.32$ mm

$P = \frac{\pi}{4} D^2 \cdot p = \frac{\pi}{4}(400)^2 * 2 = 251327.4$ N

load effected on studs for (n) number of studs

$P = \frac{\pi}{4}(d_c)^2 \cdot \sigma_t \cdot n = \frac{\pi}{4}(20.32)^2 * 35 * n = 11350.25\, n$

$n = 251327.4 / 11350.25 = 22.14$

The nearest even number of $n = 24$

Taking diameter of stud hole as $d_1 = d + 1 = 24 + 1 = 25$ mm

$Dp = D + 2t + 3d_1 = 400 + 2*10 + 3*25 = 495$ mm

Circumferential Pitch of stud $= \frac{\pi Dp}{n} = \frac{\pi * 495}{24} = 64.8$ mm

checking the design:

For leak proof joint , the value of circumferential Pitch of studs should be lies between $20\sqrt{d_1}$ and $30\sqrt{d_1}$

$\therefore$ Min. circumferential Pitch $= 20\sqrt{d_1} = 20\sqrt{25} = 100$

Max. circumferential Pitch $= 30\sqrt{d_1} = 30\sqrt{25} = 150$

$\therefore$ The design is not in Safe .

Assume that M30 , from table 11.1 , $dc = 25.706$ mm

$P = \frac{\pi}{4}(d_c)^2 \cdot \sigma_t \cdot n = \frac{\pi}{4}(25.706)^2 * 35 * n = 251.327.4$

$n = 13.8 \sim 14$ as the nearest even number

Taking dia. of stud hole as $d_1 = d + 1 = 30 + 1 = 31$ mm

$Dp = D + 2t + 3d_1 = 400 + 2*10 + 3*31 = 513$ mm

$C.P = \frac{\pi Dp}{n} = \frac{\pi * 513}{14} = 115.1$ mm

checking :

$20\sqrt{d_1} = 20\sqrt{31} = 111.35$ mm

$30\sqrt{d_1} = 30\sqrt{31} = 167.$ mm

$\therefore$ the design was in Safe at 115.1

$\therefore$ M30, $n = 14$ ans

10- load acting on cylinder head:

$$P_2 = \frac{\pi}{4} D^2 \cdot p = \frac{\pi}{4}(300)^2 * 1.5 = 105975\ N$$

Initial load:

$$P_1 = 1.8 P_2 = 1.8 * 105975 = 190755\ N$$

Resultant load (P_{max}) on cylinder head

$$P_{max} = P_1 + K \cdot P_2 = 190755 + 0.5(105975) = 243742.5\ N$$

$$P_{max} = \text{for one bolt} = \frac{243742.5}{8} = 30467.813\ N$$

$$P_{min} = \text{for one bolt} = \frac{190755}{8} = 23844.375\ N$$

$$P_m = \frac{P_{max} + P_{min}}{2} = \frac{30467.813 + 23844.375}{2} = 27156.094\ N$$

$$P_v = \frac{P_{max} - P_{min}}{2} = \frac{30467.813 - 23844.375}{2} = 3311.719\ N$$

$$\sigma_m = \frac{P_m}{A} = \frac{P_m}{\frac{\pi}{4} d_c^2} = \frac{4 P_m}{\pi \cdot d_c^2} = \frac{4 * 27156.094}{\pi\ d_c^2} = \frac{34593.75}{d_c^2}$$

$$\sigma_v = \frac{P_v}{A} = \frac{P_v}{\frac{\pi}{4} d_c^2} = \frac{4 P_v}{\pi\ d_c^2} = \frac{4 * 3311.719}{\pi \cdot d_c^2} = \frac{4218.75}{d_c^2}$$

By using Soderberg's Method:

$$\frac{1}{f.s} = \frac{\sigma_m}{\sigma_y} + \frac{\sigma_v * k_f}{\sigma_e}$$

$$\frac{1}{2} = \frac{34593.75/d_c^2}{350} + \frac{(4218.75 * 3)/d_c^2}{240}$$

$d_c = 15.2\ mm$

from table 11.1, we obtain that the standard value for $d_c = 15.2$, M20 ans

12- load on each stay:

P = Area * Pressure = $200 * 150 * 1 = 30000$ N/mm^2

The resisting force on the bolts

$P = \frac{\pi}{4} d_c^2 \cdot \sigma_t$

$30000 = \frac{\pi}{4} d_c^2 * 34$

$dc = 33.52$ mm

from table 11.1, we obtain M39

13- from table 11.1 $dc = 36.416$ mm

$d = \sqrt{D_o^2 - D_c^2} = \sqrt{(42)^2 - (36.416)^2}$

$= 20.925$ mm

14- Direct tensile load on each bolt:

$W_{t_1} = W/n = W/4 = 0.25\,W$

Load in bolt per unit distance:

$\omega = \frac{W \cdot L}{2[L_1^2 + L_2^2]} = \frac{W(200)}{2[(80)^2 + (240)^2} = \frac{W}{640}$

The heavily loaded bolt at a distance (L_1)

$W_{t_2} = \omega \cdot L_1 = \frac{W}{640} * 80 = 0.125\,W$

$W_{t\,Total} = W_{t_1} + W_{t_2}$

$= 0.25\,W + 0.125\,W = 0.375\,W$

$W_{t\,Total} = \frac{\pi}{4} d_c^2 \cdot \sigma_t$

$0.375\,W = \frac{\pi}{4}(9.858)^2 * 60$

$W = 12.212$ KN ans)

15- $W_S = \frac{W_{total}}{n} = \frac{22.5*2*10^3 + 900}{4} = 11475\ N$

Let the loads 22.5kN at the center of the pulley

$W_A = 22.5*2*10^3 = 45*10^3\ N$

$W_B = 900\ N$

The load on belts per unit distance:

$$\omega = \frac{W_A*L_A + W_B*L_B}{2[L_1^2 + L_2^2]} = \frac{45*10^3*450 + 900*375}{2[\frac{1}{2}(75)^2 + (525)^2} = 36.6\ N/mm$$

Heavily loaded bolts at the distance L_2 :

$W_{ts} = \omega . L_2 = 36.6 * 525 = 19215\ N$

$$W_{se} = \frac{1}{2}[(W_t)^2 + 4(W_s)^2]^{1/2}$$

$$= \frac{1}{2}[(19215)^2 + 4(11475)^2]^{1/2} = 14966\ N$$

$$W_{se} = \frac{\pi}{4} d_c^2 . \tau$$

$$14966 = \frac{\pi}{4} d_c^2 * 25$$

$$dc = 27.6\ mm$$

16 – $W_s = \frac{W}{n} = \frac{40 * 10^3}{4} = 10000\ N$

the Load on bolts per unit distance

$$\omega = \frac{W \cdot L}{2\left[L_1^3 + L_2^2\right]} = \frac{40 * 10^3 * 600}{2\left[(75)^2 + (575)^2\right]} = 35.69\ N/mm$$

Heavily loaded bolts at distance l_2

$W_t = 35.69 * 575 = 20520.45\ N$

$$W_{te} = \frac{W_t}{2} + \frac{1}{2}\left[(W_t)^2 + 4(W_s)^2\right]^{1/2}$$

$$= \frac{20520.45}{2} + \frac{1}{2}\left[(20520.45)^2 + 4(10000)^2\right]^{1/2}$$

$$= 24587.55\ N$$

$$W_{te} = \frac{\pi}{4} d_c^2 \cdot \sigma_t$$

$$24587.55 = \frac{\pi}{4} d_c^2 * 70$$

$$d_c = 21.153$$

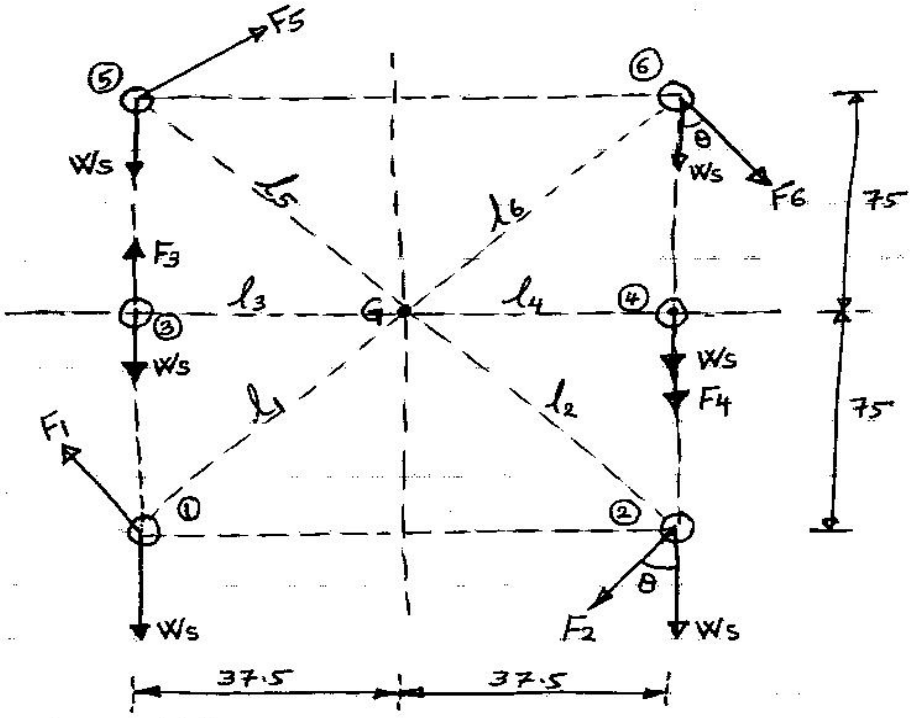
17-

Direct stress

$W_s = \frac{W}{n} = \frac{50*10^3}{6} = 8333.34N$

Turnning Moment produced by the Load W

$T = W.L = 50*10^3 * 150 = 7500*10^3$ N.mm



$L_1 = L_2 = L_5 = L_6 = \sqrt{(75)^2 + (37.5)^2} = 83.85$ mm

$L_3 = L_4 = 37.5$ mm

$W.L = F_1 * L_1 + F_2.L_2 + F_3.L_3 + F_4.L_4 + F_5.L_5 + F_6.L_6$

But $\frac{F_1}{L_1} = \frac{F_2}{L_2} = \dots = \frac{F_n}{L_n}$

$\therefore F_2 = F_1 * L_2/L_1$ $\cos\theta_2 = \cos\theta_6 = W_s/F_2 = 8333.34/20327.27 = 0.41$

$\therefore W.L = \frac{F_1}{L_1}(L_1^2 + L_2^2 + L_3^2 + L_4^2 + L_5^2 + L_6^2)$

$7500*10^3 = F_1/83.85\ (4L_1^2 + 2L_4^2)$

$7500*10^3 = F_1/83.85\ [4*(83.85)^2 + 2(37.5)^2]$

$F_1 = 20327.27N$

$F_1 = F_2 = F_5 = F_6 = 20327.27N$

$F_3 = F_4 = F_1 / L_3/L_1 = 20327.27*375 / 83.85 = 9091N$

From fig. The direct and secondary shear on each bolt, the heavily loaded bolts are(2,4,6).

The resultant shear: $R_2 = R_6 = [(W_s)^2 + (F_2)^2 + 2W_s.F_2\cos\theta]^{1/2}$

$R_2 = [(8333.34)^2 + (20327.27)^2 + 2*8333.34*20327.27*0.41]^{1/2}$

$= 24930.8N$

$R_4 = W_s + F_4 = 8333.34 + 9091 = 17424.34N$

Max. Resultant at bolt 6&2

$24930.8 = \frac{\pi}{4} d_c^2 * 150 \Rightarrow d_c = 14.5$ mm

18- $W_{t_1} = \frac{W}{n} = \frac{2.2+4.125}{4} = 1612.5\ N$

$W.L = (\omega . L_1)L_1 * 2 + (\omega . L_2)L_2 * 2$

$\omega = \frac{W.L}{2[L_1^2 + L_2^2]} = \frac{6.45 * 10^3 * 250}{2[(150)^2 + (200)^2]} = 18.97\ N/mm$

$W_{t_2} = \omega . L_2 = 18.97 * 200 = 3794.12\ N$

$W_t = W_{t_1} + W_{t_2} = 1612.5 + 3794.12 = \frac{\pi}{4} d_c^2 * 50$

$d_c = 13.546\ mm$

× × × × × × × ×

19- $L = e - R = 1250 - 300 = 950\ mm$

Max. load on bolt:

$W_t = \frac{2WL(R+r)}{n(2R^2 + r^2)}$

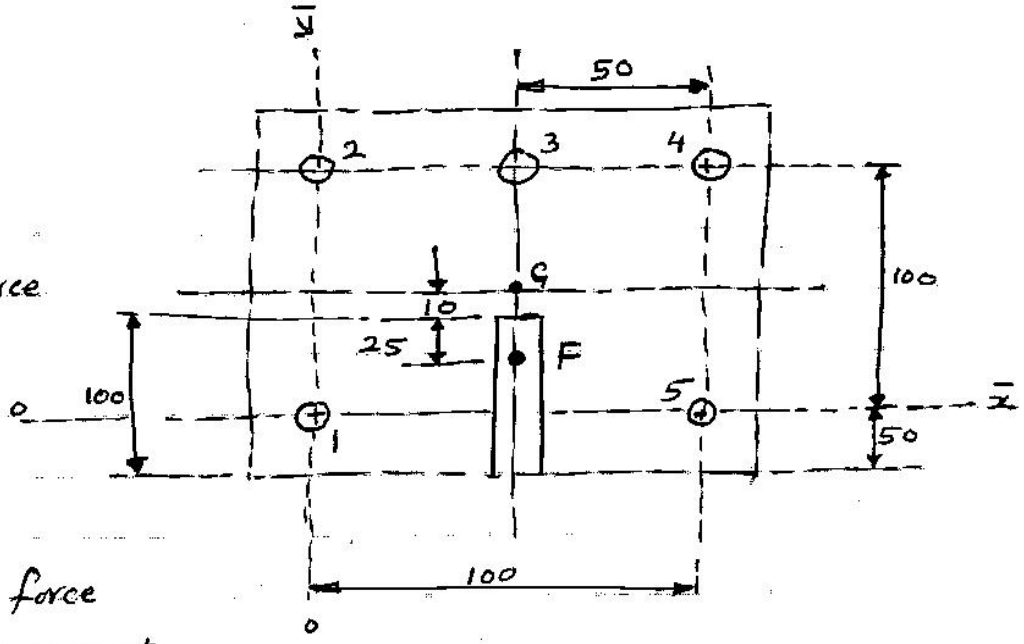
$= \frac{2 * 60 * 10^3 * 950(300+250)}{4[2*(300)^2 + (250)^2]} = 64639.17\ N$

$W_t = \frac{\pi}{4} d_c^2 . \sigma_t$

$64639.17 = \frac{\pi}{4} d_c^2 * 100$

$d_c = 28.688\ mm$

20-



$\bar{x} = 50$ mm

$\bar{y} = 60$ mm

for horizontal force

$W_{t_1} = \frac{F_H}{n}$

$= \frac{F\sin 60}{5}$

$= 7794.23 N$

The horizontal force causes turnning moment counterclock wise : $T_H = F_H * 35 = 45\sin 60 * 35 = 1363950$ N.mm

For vertical force : $W_s = \frac{F\cos 60}{n} = \frac{45\cos 60}{5} = 4500$ N

Turning Moment due to vertical force

$T_V = 45\cos 60 * (175+20) = 4387500$ N.mm (ccw)

Net turning : $1363950 + 4387500 = 3023550$ N.mm (ccw)

load on each bolt per unit distance :

$$\omega = \frac{W \cdot L}{2\left[L_1^2 + 3L_2^2\right]} = \frac{3023550}{2(50)^2 + 3(150)^2} = 41.7 \text{ N/mm}$$

Max load at L_2 : $W_{t_2} = \omega \cdot L_2 = 41.7 * 150 = 6255.62$ N

$W_{t_{Total}} = W_{t_1} + W_{t_2} = 7794.23 + 6255.62 = 14049.85$ N

$$W_{te} = \frac{1}{2}\left[W_t + \left[(W_t)^2 + 4(W_s)^2 \right]^{1/2} \right]$$

$$= \frac{1}{2}\left[14049.85 + \left[(14049.85)^2 + 4(4500)^2 \right]^{1/2} \right] = 15367.56 N$$

$W_{te} = \frac{\pi}{4} d_c^2 * 70 \Rightarrow d_c = 16.718 \Rightarrow M20$

For $W_{se} = \frac{1}{2}\left[(W_t)^2 + 4(W_s)^2 \right]^{1/2} = \frac{1}{2}\left[(14049.85)^2 + 4(4500)^2 \right]^{1/2} = 8342.6 N$

$W_{se} = \frac{\pi}{4} d_c^2 * 70 \Rightarrow d_c = 14.57 \Rightarrow M16$